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FUEL ETHANOL AND TORULA YEAST FROM CONIFEROUS WOOD BIOMASS - THOMPSON FALLS, MONTANA

Prepared for

MONTANA DEPARTMENT of NATURAL RESOURCES and CONSERVATION

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FUEL ETHANOL AND TORULA YEAST FROM CONIFEROUS WOOD BIOMASS- THOMPSON FALLS, MONTANA

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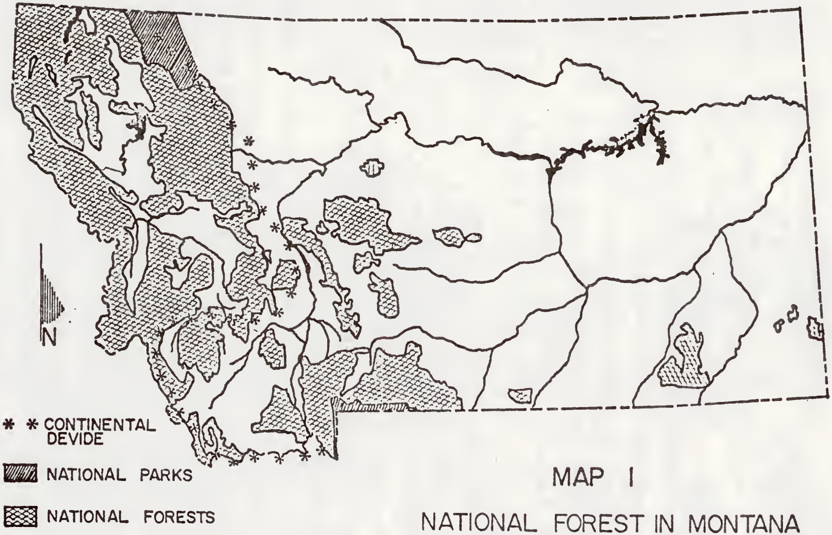
INTRODUCTION

The information contained herein represents a detailed conceptual plan, design criteria, and plant description for the collection and processing of wood waste for the production of fuel grade ethanol and torula yeast. Further, an economic analysis is presented for the establishment of such a plant on a scale consistant with the availability of wood feedstock in Thompson Falls, Montana.

Coniferous wood waste feedstock suitable for fuel grade ethanol (FGE) production in Thompson Falls is available in several forms. These include mill residues and forest residues. Mill residues consists of the wood materials from manufacturing plants that were not utilized for the mills primary product. This includes slabs, edgings, trimmings, uncuts, shavings, sawdust, and bark.

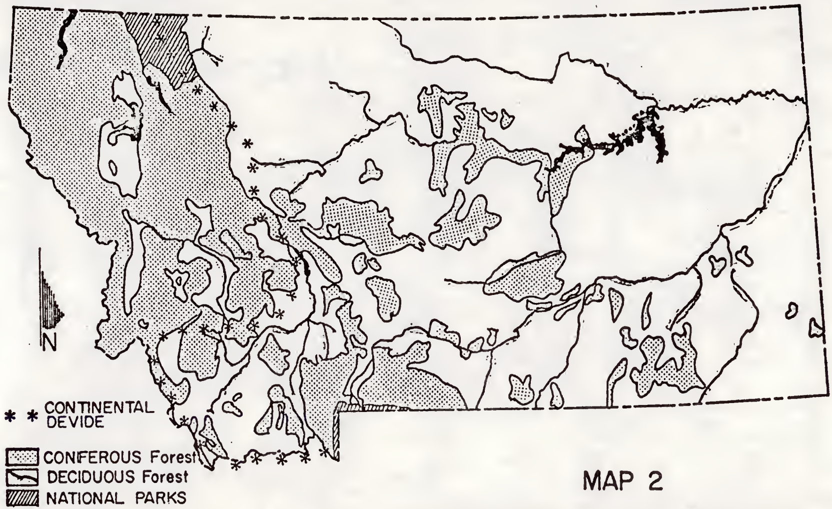
In Sanders County, Montana, five lumber mills operate with a combined annual milling capacity of approximately 150 million board feet. The combined wood waste produced by these mills is approximately 133,000 oven dry tons (ODT) per year. In addition to these major mills, there are a variety of smaller wood product manufacturers which have wood wastes available.

Forest residue represents a substancial quantity of wood in northwestern Montana. Most of the available forest residues are not presently being utilized commercially. An estimated 2.5 million tons of forest residue is currently



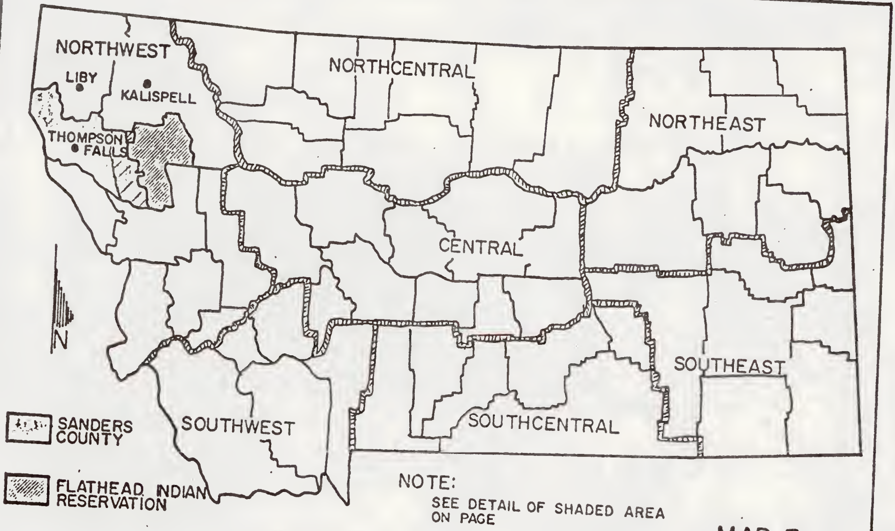
MAP I

NATIONAL FOREST IN MONTANA



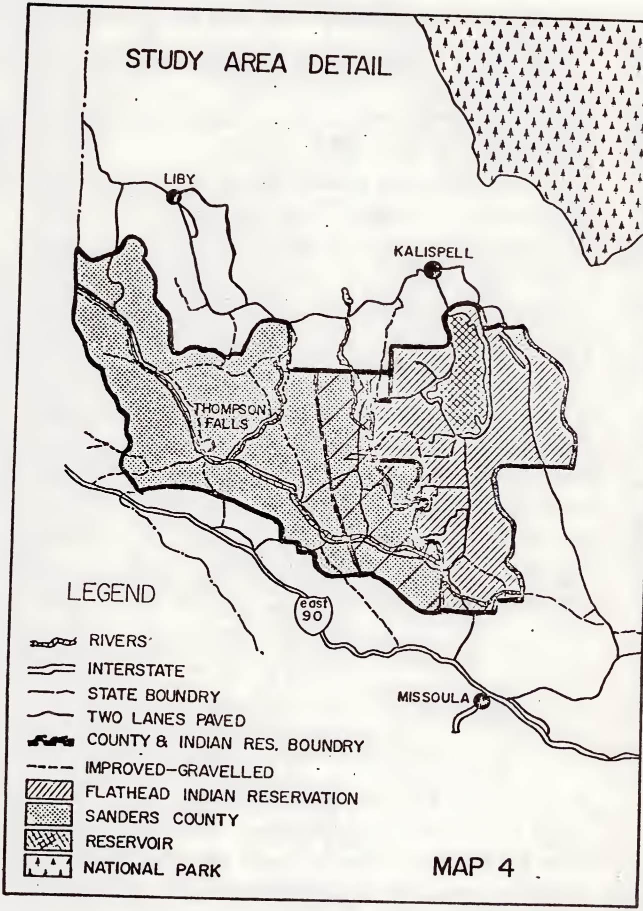
MAP 2

FORESTED LAND IN MONTANA



MAP 3

STUDY AREA


STUDY AREA DETAIL
LIBY
KALISPELL
THOMPSON FALLS
east 90
MISSOULA
LEGEND
RIVERS
INTERSTATE
STATE BOUNDRY
TWO LANES PAVED
COUNTY & INDIAN RES. BOUNDRY
IMPROVED-GRAVELLED
FLATHEAD INDIAN RESERVATION
SANDERS COUNTY
RESERVOIR
NATIONAL PARK
MAP 4

available within the Thompson Falls District of the Lolo National Forest. The currently available timber resources alone, not including commercially available wood wastes, would be adequate to operate the proposed FGE production plant for seventy-five years.

The technology for converting wood cellulose to ethanol has been available for many years. During World War I, plants at Fullerton, Louisiana and Georgetown, South Carolina were built to use sawdust and other mill wastes for ethanol production. During World War II, after European countries demonstrated the practicality of using wood derived ethanol as a motor fuel, the United States Government sponsored the construction of a ethanol from wood plant in Springfield, Oregon. Since this time there have been many technological advancements that have not only made the conversion of wood cellulose to ethanol more efficient, but economical as well. The task then was to determine which particular combination of technologies would be most appropriate for the conversion process at the proposed facility in Thompson Falls. As a result, Brelsford Engineering Inc. (BEI) recommended three processes for preliminary evaluation. They were:

1. USDA Forest Products Laboratories"Madison Acid Process"
2. U.C. Lawrence Berkeley Laboratories "Bioconversion Enzyme Process"
3. Purdue/Tsao "Acid Solvent Process"

As a result of this technological assessment, BEI recommended a combination of the currently available technologies. The process identified for further development is a modified dilute acid hydrolysis (hereafter described as the BEI process) where the wood feedstock would be pretreated by autohydrolysis. The adaptation of this autohydrolysis delignification phase not only increases the glucose recovery above that of the conventional dilute acid pretreatment, but also produces a relatively pure form of lignin. This is important because such lignin has considerable market potential as a valued industrial raw material.

The initial economic review of the BEI Process was encouraging when it was assumed that: 10%, 20%, or 30% equity would be required and did exist, that production of FGE would be 2.4 million gallons per year, and that factory door selling prices of $2.00/gal and $2.25/gal with tax credits would make $ .90/gal and $1.10/gal available to the wholesale distributor. As a consequence, further economic and techical data on the BEI Process was generated. This data included: material and energy balances, plant design criteria, raw materials and products, the conceptual plant discription, capital investment (including the costs of cogeneration equipment), operating costs, environmental factors, and another economic review.

Thus having the production capabilities of the facility established at 2.4 million gallons per year of FGE, 2300 tons per year of Torula Yeast, and approximately 5 megawatt hours of electricity, a review of the products respective markets was made.

Under current conditions - the rapid decline of imported Canadian crude oil to Montana refineries, growing state demand for gasoline, and the continuous rise in gasoline prices at the pump, comsumer demand for FGE is good. If trends continue, by 1986 a potential demand for over 60 million gallons per year could exist in Montana alone.

Torula Yeast has many applications and potential applications in the food products industry helping to stabilize it's current demand. This demand appears good as evidenced by one consumers expressed desire to negotiate for the plants entire production of yeast. Long term demand for Torula Yeast should grow steadily if the food products industry is made more aware of its multiple uses and the economics of using it as an alternate ingredient. Further potential lies in the development of foreign markets in protein deprived nations.

As a result of recent legislation, the Bonneville Power Administration is now able to enter into purchase agreements with producers generating power under 50 megawatts.

For the purposes of determining the economic feasibility of the proposed facility, several potential product and equipment configurations were examined. These configurations are briefly described below:

PLANT CONFIGURATION #1

2.4 MMGAL/YR FGE and 2300 TPY fodder grade Torula Yeast.

PLANT CONFIGURATION #2

2.4 MMGAL/YR FGE, 2300 TPY food grade Torula Yeast, conversion to stainless steel fermentation components.

PLANT CONFIGURATION #3

2.4 MMGAL/YR FGE, 2300 TPY fodder grade Torula Yeast, equipment modified to use Stake Autohydrolysis components rather than dilute acid pretreatment.

PLANT CONFIGURATION #4

2.4 MMGAL/YR FGE, 2300 TPY fodder grade Torula Yeast with addition of cogeneration equipment.

PLANT CONFIGURATION #5

2.4 MMGAL/YR FGE, 2300 TPY food grade Torula Yeast with addition of cogeneration equipment and reduction of additional feedstock costs for cogeneration to $15 per oven dry ton (ODT)

Computations were made for the net present value with rates of return at 10% and 15% and the internal rate of return for each plant configuration. Results from this analysis were positive and recommendations for further project development were made.

RESOURCE STUDY

AVAILABILITY OF WOOD FIBER FEEDSTOCK
IN
SANDERS COUNTY, MONTANA

In Montana there are two potential sources of wood fiber needed for the production of fuel grade ethanol. They are the mill residues generated from the wood product industries and the forest and logging residues of the state forest lands. A review of the current uses, availability, quantity, and costs of each follows.

MILL RESIDUE

Nearly all manufacturers using roundwood products in Montana generate three types of wood residue: (a) coarse materials consisting of slabs, edges, and trimmings, (b) fine residues consisting of sawdust and shavings, (c) bark. Although there are both primary and secondary wood product manufacturers in Montana, 95% of the state's mill residue is generated by the primary manufacturers, the sawmills and plywood plants.

Pulp mills and chip board manufacturers are the primary consumers of chips, sawdust, and shavings. Bark is used to some extent in board manufacturing but it is primarily used as boiler fuel at the manufacturers location.

In 1976, Montana sawmills and plywood plants generated an estimated 1,630 thousand bone dry units (BDU=2400 pounds) of mill residue. This consisted of about 690 MBDUs of coarse residue, 540 MBDUs of fine residue and 400 MBDUs of bark. Of the 690 MBDUs of coarse residue, over 95% was utilized. In 1976, only slightly more than 32 MBDUs of coarse residue was utilized in Montana. In the same year 84% of the fine residue was utilized, leaving 27 MBDUs unused and 296 MBDUs of bark of the total 400 MBDUs were utilized leaving 104 MBDUs unused. Table 1 summarizes the Montana mill residue situation in 1976.

A recent expansion of the Champion International pulp mill in Missoula has created a demand for the 32 MBDUs of unused coarse material. The likelihood of more Montana lumber mills installing wood fired boilers will also increase the demand for the fine residue as a hog fuel. It is evident then that the 1976 demand for the residue from primary wood manufacturers was fairly equal to the supply. By 1982, however, this demand is likely to exceed the supply. (See Table 2)

The above has summarized the mill residue availability and demand for Montana from 1976 to 1982. The following is current data specific to Sanders County, Montana, the county of the proposed plant site.

Mill residue is available in several forms and from a variety of manufacturers in Sanders County. Five lumber mills exist within the county that have a combined annual production of 147 million board feet. In residue products, they produce 44,056 oven dry tons per year (ODT/YR) of chips, 34,240 ODT/YR of shavings and sawdust, and 23,620 ODT/YR of bark. All but 30,100 ODT/YR of shavings is available for sale and currently sold to various paper and chip board manufacturers in and out of Montana.

In addition to the five primary lumber manufacturers in the county, there are a number of small wood product operations. They produce 750 ODT/YR in chips, 3231 ODT/YR in dirty chips, 1012 ODT/YR in shavings and sawdust, and 3117 ODT/YR of trim ends and slabs. Currently there is no developed means of disposing of the 8110 ODT/YR other than stockpiling or burning. Table 3 summarizes the costs and availability of all wood product manufacturing residue in Sanders County.

When reviewing the costs of chips, it should be noted that the average of $83.87 per ODT is currently high due to the tradition of higher prices paid for pulp wood when the national demand for round wood products is low. In the past five years, prices for an ODT of chips has ranged from about $25.00 to $90.00.

FOREST RESIDUE

In 1976, approximately 938 MBDUs of presently usable logginh residue - were generated in Montana. Of 938 MBDUs, about 578 MBDUs were suitable for solid wood products with the remaining 360 MBDUs suitable as a source of wood fiber.

Montana Counties west of the divide accounted for about 817 MBDUs (87% of the state total) of logging residue in 1976. About 493 MBDUs were suitable as a raw material for solid products and the remaining 324 MBDUs were suitable as fiber. (Table 4) Most of the production was concentrated in four counties: Lincoln, Flathead, Sanders, and Missoula, with each having over 100 MBDUs of available logging residue generated in 1976. These four counties produced almost 75 percent of the total logging residue generated in Montana in 1976.

Virtually no logging residue is currently being utilized in Montana. However, users unable to satisfy their needs by mill residues will be turning more and more to forest residue. The Champion International pulp plant expansion, for example, plans to utilize annually about 90 MBDUs of forest residue as industrial fuel. Most of this will be drawn from the counties closest to the pulp mill - Missoula, Lake, Mineral, Powell, and a good portion from Flathead and Sanders.

Since the proposed fuel grade ethanol production facility is to be located in Sanders County, and it is generally considered uneconomical to transport logging residue over a distance of 75 miles, it was necessary to specifically determine the concentrations, quantities, and costs of harvesting and transporting the Sanders County logging residue to a plant site in Thompson Falls. To accomplish this, each timber sale on the county's state and Federal land in 1979 was examined, total residue was determined, and it's delivered cost to a Thompson Falls plant site was calculated. (Table 5)

As indicated by the variance of the delivered costs in Table 5, even among the two residue groups ($16.34 ODT to $43.70 ODT for large and $32.50/ODT to $107.95/ODT for small) it is evident that logging residue collection and transportation economics is very site specific.

Those variables having the greatest affect are (1) size and distribution of the residue, land slope (over 30% slope is more expensive as cable techniques must be used), (2) size of the log landings (if landings are too small, the material cannot be in-wood chipped because of limited space for additional equipment and handling), (3) distance of haul, (4) road conditions (gravel and dirt roads as well as sharp winding roads increase transportation costs and limit the type of equipment that can be used), (5) the quantity of residue still standing and needing to be felled.

Because each site condition varied, the methods of harvesting varied somewhat also. It became evident that the most economical method of harvesting residue in Sanders County was to skid the whole tree during the normal round wood harvest operation, then remove and in-wood chip the top at the landing site. This procedure effectively eliminates the large skidding costs necessary if the tops and stems were removed before skidding.

Other methods of harvesting were reviewed and the results are presented in Table 6. Basically, tractor yarding proved more economical than cable yarding and in-wood chipping more economical than in-plant chipping.

For the purpose of this study, it was assumed that the equipment selected for the roundwood harvest of the site would also be suitable for the residue harvest. The equipment costs and capabilities assumed in this study are as follows:

EQUIPMENT	COST	CAPABILITY
Tractor skidder and operator	$25.80 per hour	10 piece load per turn, 150 ft.^{3} maximum
Cable yarding equipment and 4 man crew	$800 per day	yarding distance to 1,000 ft. The number of pieces of residue per shift is estimated as $N = (208 - 2V)$ per piece of 0.4 to 50 ft. V = volume per piece
Loading and hauling (truck and driver loader and operator)	$46.00 per hour	52,000 pound load - loading time of 50 minutes for large pieces, 125 minutes for small pieces
In-wood chipper and operator, front end loader and operator	$60.00 per hour	8.3 cunits of chips per hour
In-plant chipper, operator and limited yard handling	$6.25 per cunit	--

Although logging residue may at present be the most accessable form of forest residue, there are others. Untreated slash from previous years logging operations in Montana is estimated to be at least two million bone dry unites and approximately 10% of that is in Sanders County. Dead material is by far the largest residue component in Montana. In 1974, there were an estimated 14 billion board feet of salvagable dead timber with an annual mortality of 585 million board feet. Specifically, in Sanders County's Lolo National Forest in 1979 were 2,453,487 oven dry tons of dead and fallen timber.

Other potential sources include submerchantable material from thinnings and related forest management activities.

TABLE I

MILL RESIDUE FROM LUMBER AND PLYWOOD PLANTS IN MONTANA 1976

(Thousand Bone Dry Units)

	UTILIZED	UNUSED	TOTAL
COARSE RESIDUE (Chippable Materials)	658	32	690
FINE RESIDUE			
Shavings	228	27	255
Sawdust	225	60	285
BARK	296	104	400
TOTAL	1407	223	1630

TABLE II

PROJECTED ANNUAL SUPPLY AND DEMAND OF MILL RESIDUE IN MONTANA 1982

(Thousand Bone Dry Units)

	COARSE	FINE	BARK	TOTAL
Supply from sawmill and plywood plants in Montana	690	540	400	1630
Less:				
Expected Demand From Pulp Mills and Board Plants	874	500		1374
Portion of supply from Montana committed to other states	100			100
Expected Demand for Hog Fuel		200	350	550
Projected Residue Excess (deficit) from Montana Sawmills and Plywood Plants	284	160	50	394

QUANTITY, TYPES, AND COSTS OF MILL WOOD RESIDUE IN SANDERS COUNTY, MONTANA
1980

	Residue Type									
	Bark		Chips		Dirty Chips (max. 50% bark)		Shavings, Sawdust		Trim Ends & Slabs	
	Cost and Quantity									
MANUFACTURER	$/odt	odt/yr	$/odt	odt/yr	$/odt	odt/yr	$/odt	odt/yr	$/odt	odt/yr
Louisiana Pacific			85.66	12,000						
Flodin	4.16	3,600	83.00	10,440			5.00	8100		
W.I. Forest Products	4.16	18,000	83.33	16,000			5.00	22,000		
Vinson Timber	5.33	1,440	83.33	5,616			5.33	3240		
Watters Lumber Co.	4.16	580					4.58	900	20.00	1160
National Log					2.77	2791				
R & R Industries			83.33	750						
Carlson Sawmill							7.33	337	20.00	652
Thompson River Forest							5.00	675	20.00	1305
Custer Post and Pole					2.00	125				
K & H					4.16	325				
TOTAL ODT/YR AVERAGE $/ODT	4.23	23,620	83.87	44,806	2.88	3,231	5.04	*35,252	20.00	3,117

ODT = Oven Dry Ton
Prices are F.O.B. Thompson Falls
*30,100 ODT of total 35,252 ODT not available for sale

TABLE IV

LOGGING RESIDUE OVER THREE INCHES IN DIAMETER AND EIGHT FEET IN LENGTH

MONTANA 1976
(Thousand Bone Dry Units)

	Suitable for Solid Products	Suitable as Fiber	Total Logging Residue
Counties West of the Divide			
Lincoln	149	96	245
Flathead	124	76	200
Sanders	67	51	118
Missoula	66	50	116
Mineral	22	16	38
Lake	20	14	34
Powell	19	8	27
Ravalli	10	6	16
All Others	16	7	23
Counties East of the Divide			
Gallatin	27	10	37
Beaverhead	13	6	19
Meagher	12	5	17
Park	11	5	14
Lewis and Clark	9	5	14
Jefferson	9	3	12
All Others	4	2	6
Total	578	360	938

TABLE V:

Total Residue Volume and Delivered Cost* for 100% Recovery on Sanders County State and Federal Lands
(Based on 1979 volume, 1978/$)

HARVEST SITE Nat'l. Forest/District or State	RESIDUE TYPE: Large (10-16" DBH whole stem)		Small (6" large end dia., 24' long)	
	COST AND QUANTITY: $/ODT	ODT/YR	$/ODT	ODT/YR
Lolo / Plains	28.19	4485	91.60	1951
Lolo / Plains	37.95	10550	107.95	2193
Lolo / Plains	36.96	3991	95.08	2462
Lolo / Thompson Falls	29.18	2771	87.11	1818
Lolo / Thompson Falls	21.00	5210	99.26	623
Lolo / Thompson Falls	43.70	5535	104.72	1846
Kootenai / Trout Creek			49.99	1467
State	16.34	4621	32.50	355
State	26.70	162	39.18	434
State			45.79	528
State			43.30	1165
Total ODT/YR		37,325		14,842
Average $/ODT	31.78		83.52	

* Delivered cost to Thompson Falls plant site
Assume 20% increase in above costs due to material breakage in handling

TABLE VI

AVERAGE COSTS OF RESIDUE (LARGE AND SMALL) FOR DIFFERENT HARVEST TECHNIQUES AND % OF TOTAL VOLUME (52,167 odt) FROM SANDERS COUNTY, STATE AND FEDERAL LANDS

(1979 volume, 1978/$)

HARVEST TECHNIQUE	Tractor Skid w/ in plant chip		Tractor Skid w/ in wood chip		Whole Tree Skid w/ in plant chip		Whole Tree Skid w/ in wood chip	
RESIDUE TYPE	Large	Small	Large	Small	Large	Small	Large	Small
QUANTITY (ODT/YR)	3956	2089	12,462	6069		5948		7840
AVERAGE COST ($/ODT)	28.60	48.37	24.88	41.22		29.27		21.47
%OF TOTAL VOLUME (52,167 ODT/YR)	7.6	4.0	23.9	11.7		11.4		15.0

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PROCESS IDENTIFICATION
PRELIMINARY ENGINEERING AND ECONOMICS

BACKGROUND

In [illegible], [illegible]ord Engineering conducted a "Technology Assessment of Fuels from Montana Crops and Crop Residues" for the Montana Alternative Renewable Energy Sources Program (RAE 700-BRLFD-77).[4] This engineering research project involved a phased examination of the status of and potential for the production of gaseous, liquid and solid fuels from Montana agricultural biomass, which included wood waste but did not include animal wastes. In the second and final phase, investigations were particularly oriented to the hydrolysis and fermentation of agricultural biomass for the production of fuel grade ethanol (here-in-after referred to as FGE).

As a direct result, the three processes that were recommended for preliminary evaluation and ranking as to their particular applicability and compatability to a wood waste to FGE processing plant in Thompson Falls, Montana were:

1. USDA Forest Products Laboratory's Madison Acid Process
2. UC Lawrence Berkeley Laboratory's Bioconversion Enzyme Process
3. Purdue/Tsao Acid Solvent Process

This report includes a discussion, evaluation and ranking as well as recommendations related to these processes and their suitability and applicability for the development of a small-scale facility for the production of FGE from wood waste in Thompson Falls, Montana.

ACID HYDROLYSIS

Scholler Process

The first Scholler process plant, built in Germany in 1934, recovered about 1,000 pounds of sugars from a ton of dry waste wood; sufficient to make about 50 to 60 gallons of ethanol or about 500 pounds of dry feed yeast containing 50% protein.[3] Steel hydrolyzers, 45 feet high and 8 feet in diameter, were charged with 10 to 12 long tons of sawdust and other wood wastes under low steam pressure. The hydrolyzers were lined with acid resistant brick. After the contents were preheated to 265 F., a 0.8% solution of sulfuric acid was introduced at the top and forced through the wood under 35 p.s.i. Sugar solution was withdrawn at the bottom. Final batches went through at about 375 F. and 180 p.s.i. The water-to-wood ratio was 12 to 1. This 10 ton/cycle batch, over a period of 16 to 24 hours, resulted in about 30,000 gallons of wort of 3 to 4% sugar, about 80% fermentable to ethanol. After neutralizing, the wort (hydrolyzate) was filtered and was then ready for fermentation into ethanol or for growing yeast into a fodder yeast product. In each hydrolyzer there was a residue of about 6,000 pounds of lignin (600 pounds per ton of wood), which was expelled by steam pressure into a cyclone. The lignin thus produced was a fine, brown powder. Hydrolyzate, emerging from the hydrolyzers at about 334 F., flowed through coil heat exchangers to preheat water used for subsequent batches. This entire cycle required about 24 hours, each acid batch remaining in the cylinder from 45 to 90 minutes.

Three Scholler plants were built in Germany: at Tornesch, in 1934, capacity 25 tons of wood per day; at Holzminden, in 1937, capacity 60 tons of wood per day; and at Dessau, in 1937, capacity 60 tons of wood daily. Other plants were built at Ems, Switzerland, and in Korea. The relatively new Ems plant (probably the only Scholler plant operating in 1952) was modernized further since the war so that operation cycles would be less than half as long as those used by the Germans; thus the capacity of this plant was double the original 60 tons per day capacity.

Madison Process

Because of the need for a nonfood source of sugar for the production of ethanol during World War II, the Office of Production Research and Development of the U.S. War Production Board in 1943 instituted an investigation of the hydrolysis of wood by the U.S.D.A. Forest Products Laboratory in Madison, Wisconsin.

Using the short-cycle, acid-hydrolysis procedure, sugar concentrations of 4 to 5.5 percent were obtained by using total waste to wood ratio of 8 to 1. The yields of 95 percent ethanol based on the wood are given in Table 1.

Table 1

YIELD OF SUGAR AND ALCOHOL USING SHORT-CYCLES

Species	Yield of Sugar (%)	Yield of Alcohol (gal/ton)
White spruce	49.9	59.0
Douglas-fir	49.0	56.6
Ponderosa pine	50.5	51.3

Source: Reference 18

Douglas-fir with varying amounts of bark was hydrolyzed to determine the effect of bark on the yield of sugar. Bark which contained 26.4 per cent potential sugar gave only 18 percent sugar on hydrolysis while bark-free wood with 67.5 percent potential sugar gave 59 to 51 percent sugar. Chipped slabs contained 34.6 percent bark yielded 38.7 percent sugar.

In the United States in 1946, a plant using 220 tons of dry wood wastes daily, based upon the Madison process, was designed and erected in Springfield, Oregon to supply the infant synthetic rubber industry during World War II.[1, 22] The Madison process provided significant improvement over the Scholler process. Introduction of acid and removal of sugar solution was continuous and required 4 to 5 hours. Lignin, after being blown into a cyclone, was pressed to a moisture content of 50% and then used as fuel in the boiler.

Figure 1 is a simplified schematic flow diagram of the Madison process. The biomass feedstock is discharged from the live storage hopper of the standard front-end unit into a digester. Live steam is then introduced raising the temperature to about 275°F (125°C) at which point sulfuric acid and a recycled dilute prehydrolyzate stream are introduced followed by hot water. The contents are maintained at 275° to 300°F (135° to 150°C) for 30 minutes. The prehydrolyzate is drained, and dilute sulfuric acid introduced at the top of the digester in conjunction with high-pressure (250 psig) steam to raise the temperature to 300°F (150°C) in order to begin the main hydrolysis. The main hydrolysis is carried on for 3 hours and during this time the reaction temperature is raised from 150°C to 190°C.[14]

Methanol and furfural contained in the vapors resulting from "flashing" the solution to lower pressure are separated in a distillation tower. The hot hydrolyzate is neutralized with lime and the calcium sulfate precipitate separated. A wash cycle is used on this precipitate to recover a small amount of sugar. The sugar is passed to fermenting tanks for alcohol or yeast production, but can be concentrated to crude molasses.

The economics of the Madison acid hydrolysis process were analyzed in 1975, by Raphael Katzen Associates, for the USDA Forest Products Laboratory.[17] The resulting estimated production plant characteristics for an 850 oven-dry-ton (ODT) per day acid-hydrolysis and fermentation plant for the production of ethanol is shown in Table 2. The product is basically 190 proof (95 percent) ethanol. There is a considerable amount of sludge, primarily calcium sulfate, to be disposed of daily.

The total 1975 capital investment and annual operations and maintenance costs have been estimated for three sizes of plants as shown in Table 3. No credit is taken for by-products or co-products that can be produced simultaneously along with the ethanol.

ETHANOL FROM WASTE WOOD

PROCESS STEPS

1. CELLULOSE CONVERTED TO SUGAR BY ACID HYDROLYSIS UNDER HIGH PRESSURE AND TEMPERATURE.
2. SUGAR SOLUTION FLASHED.
3. FURFURAL IN FLASH CONDENSATE RECOVERED.
4. SUGAR SOLUTION NEUTRALIZED.
5. CALCIUM SULFATE SEPARATED.
6. SUGARS (6 CARBON TYPE) FERMENTED TO ETHANOL AND CARBON DIOXIDE.
7. YEAST SEPARATED FOR RE-USE.
8. ETHANOL STRIPPED FROM DILUTE LIQUOR.
9. CONTAMINANTS EXTRACTED FROM ETHANOL.
10. ETHANOL CONCENTRATED TO 190 PROOF.
11. SUGARS (5 CARBON TYPE) CONCENTRATED.

Source: Reference 17

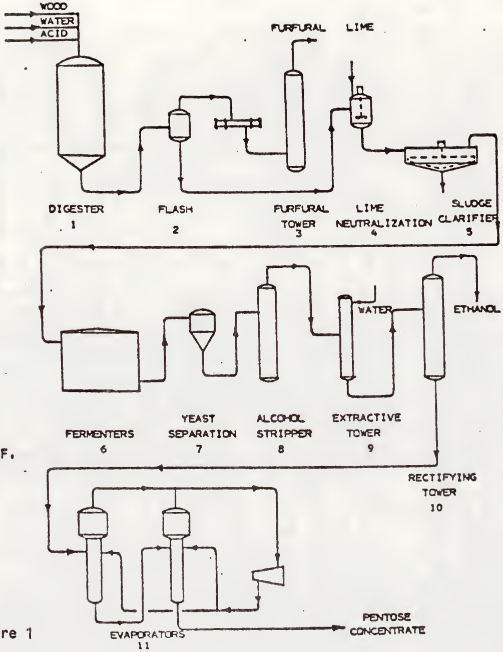

Figure 1

SIMPLIFIED SCHEMATIC FLOW DIAGRAM - ETHANOL PRODUCTION BY SULFURIC ACID HYDROLYSIS AND FERMENTATION

Table 2

CHARACTERIZATION OF AN 850 ODT PER DAY WOOD BIOMASS FEEDSTOCK ACID-HYDROLYSIS AND FERMENTATION PLANT FOR ETHANOL PRODUCTION

CHARACTERISTICS		EVALUATION
Wood Biomass Feedstock		850 ODT/day
Wood Biomass Moisture Content		50%
Heat Input		1.445×10^{10} Btu/day
PRODUCT OUTPUT		
Before Fermentation:	Hexoses	536 tons/day
	Pentoses	56.7 tons/day
	Furfural	16.6 tons/day
	Methanol	13.8 tons/day
After Fermentation:	Ethanol (190 proof)	279 tons/day 0.677×10^{10} Btu/day(1)
	Residual Sugars and Pentose	54 tons/day
Waste:	Calcium Sulfate	104 tons/day
SITE REQUIREMENTS		
Steam		525,000 lbs/hr
Electrical Power		5,000 KW
Water (evaporation)		633,000 gals/day
Sulfuric Acid 100%		92.6 tons/day
Lime (calcium carbonate)		52.5 tons/day
Diammonium Phosphate		0.4 tons/day
NH_3		6.9 tons/day
Land Area		15.0 Acres

(1) Heating value (12,780)(0.95) = 12141 Btu/lb gross.

Source: Reference 3

Table 3

CAPITAL AND OPERATING COST
PRODUCTION OF ETHANOL BY ACID-HYCROLYSIS/FERMENTATION
(costs in million dollars)

ITEM OF COST	PLANT SIZE I	PLANT SIZE II	PLANT SIZE III
Feed capacity, ODT/day	850	1700	3400
Ethanol output gallons/day @190° proof	84,400	168,800	337,600
Btu/day (gross)	0.677×10^{10}	1.354×10^{10}	2.708×10^{10}
CAPITAL COST			
Front End Process	1.50	1.71	3.16
Hydrolysis Equipment	14.61	28.35	55.26
Crude Furfural and Ethanol Equipment	.68	1.22	1.88
Fermentation Equipment	6.46	12.31	23.51
Distillation Equipment	3.42	6.14	11.05
Evaporation and Concentration Equipment	11.20	20.16	36.30
Steam Plant	20.10	32.13	51.39
Electric Generation	3.97	6.35	10.18
Water Treatment Plant	2.09	3.35	5.34
Cooling Towers	3.62	5.79	9.27
Storage and Shipping	4.16	6.66	10.63
Fire Protection	.62	.99	1.59
Instrumentation and Controls	1.80	2.88	4.60
General Mechanical	5.65	9.61	16.78
General Electrical	3.77	6.41	11.19
Buildings and Structures	2.58	3.10	4.03
Site Development	1.40	2.52	4.55
Engineering and Fee @15%	13.14	22.45	39.10
Commissioning and Contingency @15%	15.11	25.82	44.97
Working Capital @10%	11.58	19.79	34.47
TOTAL	127.46	217.73	379.25
OPERATING AND MAINTENANCE COST			
Direct Labor Cost	6.64	10.50	18.92
Labor Related Cost	5.97	9.45	17.02
Power Cost (Plant Generated)	0	0	0
Chemicals Cost	2.36	4.72	9.45
Other Utility Cost	.14	.28	.55
Maintenance Cost	6.37	10.88	18.96
Miscellaneous Equipment Repair Cost	1.27	2.17	3.79
TOTAL ANNUAL COST	22.75	38.00	68.69

Source: Reference 3

In the overall process, a solution fraction is isolated containing the pentoses formed during the hydrolysis. This fraction may have value as a raw material for furfural manufacture or as the aerobic fermentation substrate for the production of Torula yeast. Torula yeast has an established commercial market as a food and fodder feed ingredient. The economics of Torula yeast production are particularly encouraging since the current prices for food-grade Torula Dried Yeast of Monarch Paper Corporation is in the range from $0.40 to $1.46/lb. (See Appendix)

Fermentation by Torula Yeast

Torula utilis, a strain of wild yeast which was found at the Forest Products Laboratory to utilize 90 to 95% of the reducing sugar when grown on wood hydrolyzate, has been used for the ethanolic fermentation of wood hydrolyzates. Several transfers of the yeast from a completed fermentation to new sugar were required before the ethanol fermentations were as rapid and the amount of ethanol produced was as high as that obtained with S. cerevisiae.[15] Pentose sugars do not appear to be used in the alcoholic fermentation with Torula utilis, but small amounts may be being utilized to grow yeast during or after the alcoholic fermentation is complete. Pilot-plant fermentations in batch and continuous tests indicated that Torula utilis is suitable for ethanolic fermentations and is to be preferred for the fermentation of wood hydrolyzates because of its greater resistance to the inhibiting substances present. It easily maintains sufficient growth in wood hydrolyzates to replace yeast lost in the process and to provide rapid fermentation rates. The yield of ethanol from a Douglas fir wood hydrolyzate containing 5% reducing sugar was about 90% of theoretical.[14]

The Forest Products Laboratory has used Torula utilis yeast for wood hydrolyzate fermentation to ethanol and yeast (single cell protein). Brelsford developed the required substrate and aerobic fermentation process conditions and demonstrated the two-hour, exponential growth-rate of Candida utilius yeast on barley starch hydrolyzate at pilot-plant scale at Montana State University in 1964.[5, 6]

Montana Sulfuric Acid

Sulfuric acid is commercially available in industrial quantities from the Montana non-ferris metal smelters of the Anaconda Company and ASARCO, Inc. ASARCO, Inc. in East Helena, MT offers chemical grade Virgin Acid 93% 66° Baume for sale in bulk at $58/ton in tank trucks delivered. They also offer an agricultural grade Black Acid 93% 66° Baume at $16/ton FOB the plant in East Helena. For biomass hydrolysis and yeast fermentation, the agricultural grade may not be satisfactory because of toxcisity to the yeast. The other grade would undoubtedly be chemically pure and entirely satisfactory.

Prehydrolysis Process

When wood is considered as a chemical raw material, not simply an energy source, it is possible to recover the hemicellulosic pentoses (C_5) and hexoses (C_6) from wood and subsequently utilize or hydrolyze the ligno-cellulose for other products. Softwood, such as Douglas fir, contains about 25% hemicullulose, of which 20% is hexosan and 80% pentosan.

An economical way to recover hemicelluloce-based sugars from wood is a mild acid, pre-hydrolysis process. Since beta- and gamma- cellulose dissociate 100 times faster than alpha-cellulose, wood can be treated mildly to avoid destruction of the fiber, or for preparation to acid hydrolysis of ligno-cellulose.[12] A patented process has been developed by a Canadian Company, Silvichem Corporation, Ltd., for a mild treatment which does not allow operating temperatures higher than 135°C to avoid the formation of furfural. Xylose is a much more valuable product, as well as useful for the production of food and fodder Torula yeast.

Dartmouth College Developments

A continuous plug-flow reactor has been developed for acid hydrolysis of cellulosic materials. A single pass hydrolysis at 464°F (240°C) with 1% acid gave 50 to 57% glucose yield for a slurry concentration of 5 to 13.5% solids. For high xylose recovery, a two-stage hydrolysis is needed, the first stage at low temperature (180-200°C or 190 psia Steam) and the second at high temperature (230-240°C or 425 psia Steam).[10]

The flow reactor has also been used to give acid pretreatments to cellulosic materials prior to enzymatic hydrolysis. The resulting yield increase by enzymatic hydrolysis is significant for oak (21% to 90%), corn stover (58% to 100%), and newsprint (60% to 93%) as a result of the pretreatment. Thus, a combination of acid hydrolysis pretreatment with enzymatic hydrolysis can achieve nearly quantitative yields of glucose.[11]

A similar analysis for the case where wood is used as the substrate is presented in Table 4. The effect of pretreatment is more pronounced here because the wood has a much greater cost, a lower glucan content, and a greater enhancement of the conversion of pretreatment. Again, the absolute values should not be regarded as final because by-product credit is not taken.

Table 4
EFFECT OF ACID PRETREATMENT ON THE COST
OF ETHANOL FROM WOOD VIA ENZYMATIC
HYDROLYSIS WITH AND WITHOUT PRETREATMENT
(no by-product credit; 41% glucan in
feedstock costing 30$/ton)

	With Pretreatment	Without Pretreatment
Conversion of potential glucan, %	90.%	25.%
Substrate	68.3 ¢/gal	20.5 ¢/gal
Pretreatment	27.7	0
Hydrolysis	40.1	144.0
Sugar Concentration	1.5	5.4
Ethanol Production	30.3	30.3
Difference	167.9 ¢/gal	384.7 ¢/gal

Difference is 216.8¢/gal

Source: Reference 11

REPORT OF TELE-CON

By Don L Brelsford
June 24, 1980

Person Called: Dr. Alvin O. Converse
Thayer College of Engineering
Dartmouth College
Hanover, NH

SUBJECT: Acid Hydrolysis of Cellulosic Biomass

Brelsford indicated that the BEI literature search had found several of his technical articles, and had the latest one from the 3rd Annual Biomass Energy Systems Conference Proceedings of October 1979. Professor Converse indicated they would have a new final progress report of their current DOE FFB effort available next week and will send a copy to BEI.

Recent plug-flow reactor developments have been at small laboratory scale and on corn stovers. Nothing yet has been done with wood wastes but he feels the hydrolysis kinetics that have been demonstrated for plug flow reactor hydrolysis of biomass would be consistent throughout various biomass materials.

Dr. Converse indicated the Georgia Tech. Process Development Unit (PDU) was very flexible in design. Initially process development work will use the Madison process with recycle of the unhydrolyzed cellulose, but this would require delignification prior to the hydrolysis. The straight through, plug-flow reactor for acid hydrolysis is simplier and as efficient in conversion efficiencies.

Trichoderma viride and designated QM 9414. Following full growth and maturity of the fungus, the growth media is filtered and the fungal solids discharged. A clear yellow colored liquid results from the filtering and is the cellulase enzyme solution to be used in cellulose hydrolysis reactions. Hydrolysis of delignified cellulosic materials results upon immersion of the substrate into the enzyme solution.

In recent results from the LBL laboratory, the the treatment of 2 mm Wiley milled wheat straw was analyzed in a variety of ways.[27] In addition to glucose and xylose, the original material contained about 5% of other sugars, 12.5% ligin, 9.6% ash, 7.6% extractives, and 12% unknown organic material. Treatment with 1% H_2SO_4 in 7.5% solid suspension for 5.5 hours at 100°C removed most of the xylose and other sugars, with a total dry weight removal of 37.6%. Sachromyces cerevisiae yeast used in the ethanol fermentation was found at LBL to ferment only 70 percent of the reducing sugars in the hydrolyzate of wheat straw. The remaining 30 percent of the sugars (xylose and cellobiose) were fed to an aerobic fermentation process to produce single cell protein from Torula yeast. The Forest Products Laboratory has used Torula utilis yeast for wood hydrolyzate fermentation to ethanol.[14] However, for aerobically grown T. utilis, several transfers of the yeast from a completed fermentation to new wood sugars were required before the ethanol fermentation was rapid enough.

LBL has studied the continuous fermentation of glucose with Saccharomyces cerevisiae and have made a preliminary process design and cost estimate for the production of ethanol and torula yeast from the enzymatic hydrolyzate of newsprint.[26] The hydrolysis product was found to be 70% fermentable by Saccharomyces, thus required a 14.3% solution of hydrolyzate sugars to obtain the optimum feed of 10% fermentable sugars. Preliminary cost analysis showed it economically favorable to concentrate the sugar to 14.3%. The concentration costs of 2.7 cents/gal. of ethanol produced being more than offset by the savings in fermentation and distillation costs.

After the hydrolyzate sugars have been evaporatively concentrated from 4.0% to 14.3% solution, protein and mineral supplements are mixed with the sugars. A low flow of air is sparged through the fermenters to

ENZYMATIC HYDROLYSIS

Lawrence Berkeley Laboratory

At the University of California's Lawrence Berkeley Laboratory (LBL), a chemical engineering process development program for the conversion of biomass to ethanol, with particular emphasis on enzymatic hydrolysis, is underway. On the basis of available laboratory data, LBL has developed a preliminary process design and cost analysis for enzymatic hydrolysis of 885 tons per day of newsprint.[26]

The primary plant feed consists of 885 tons per day of newsprint containing 6% moisture. By means of moderate shredding and hammermilling the feed is reduced to approximately 20 mesh. An additional 66 tons per day of feed material is diverted to the first enzyme induction fermentor after sterilization with steam. The product sugar stream from the hydrolyzer is contacted counter-currently in 3 mixer-filter stages with feed solids for enzyme recovery. Each mixer filter stage consists of a mixing tank to provide 30 minutes contact time and a horizontal belt vacuum filter to separate the solids from the liquid. A total enzyme recovery of 95% is predicted by theory based on absorption studies.

For this particular conceptual design in 1975, the estimated fixed capital cost of $23,390,000 and a sugar cost of 5.2 cents per pound was obtained. At a conversion of 14 lbs. of sugar per gal. of FGE the sugar substrate cost for fermentation would be 72.3¢/gal. FGE.

Enzumatic hydrolysis is generally at atmospheric pressure and below 100°C. However, process times ordinarily are in the range of 24 to 48 hours and the form of the cellulose substrate is critical. To obtain effective conversion rates, the substrate must be delignified or very heavily milled. The U.S. Army Natick Development Center in Natick, Massachusetts, has successfully developed an enzymatic hydrolysis process for municipal waste cellulose.[19] The Natick process is based upon the use of the cellulase enzymes derived from the mutant strains of the fungus maintain the oxygen tension at the optimum level of 0.07 mm Hg. The fermented beer then passes to two continuous centrifuges and the yeast is removed. The yeast is subsequently dried and stored for sale as a protein feed supplement. The clarified beer from the centrifuges is next distilled to concentrate the ethanol to 95 wt%.

The yeast production fermentation resembles the alcohol fermentation process excluding the distillation and absorption columns. Of course the aeration and agitation rates are much higher for the production of yeast cell mass. Also the fermentors were operated at a total pressure of 2.6 atm to enhance the oxygen transfer. After the yeast has been removed from the broth by centrifugation, the yeast stream is spray dried and packaged for sale. In enzymatic hydrolysis of biomass, the primary cost factor in the feed preparation is size reduction and destruction of the crystalline cellulose. The work at Natick has demonstrated the necessity of intimate disruption of crystalline fibers as well as reduction of particle size. The cost of this operation was estimated from data which related large scale size reduction costs to average particle size achieved and was found to be about $.065 per pound of feed. The total cost of acquiring and preparing the feed is then about $.07 to $.08 per lb. of feed. The ultimate cost per pound of glucose can range from $.10 to $.20 depending on other parameters which determine the feed rate.

The second area of concern is the production of enzyme by the growth of Trichoderma viride in submerged culture fermentation. This area offers the best opportunity for improvement through fundamental and process development of any part of the process.

A preliminary cost estimate was made by LBL for ethanol and Torula yeast fermentation assuming the availability of fermentable sugars at 3 to 4% wt conc and at a cost of 5.2 ¢/lb. of sugars. The steam and power costs were estimated assuming that they would be generated using spent solids from the hydrolysis as fuel. The fixed capital cost per annual gallon of FGE production for a 7.2 mm gal/yr. plant was $0.75/gal FGE. Of the $1.05/gal post hydrolysis fermentation production cost, 68.6% is related to the sugar cost of 5.2¢/lb. For Torula yeast production, the sugar cost amounts to 39% of the yeast production cost of 30 ¢/lb. A somewhat heavy charge is made for nutrient supplements in the yeast production. The nutrient requirement assumed no vitamin or protein components as in the enzyme hydrolysate. This would probably not be true for acid hydrolysis where nutrient costs would probable be reduced.

Miles Laboratory Cellulase

Trichoderma viride cellulase enzyme for cellulose hydrolysis is commercially available from Miles Laboratories, Inc., as well as from Enzyme Development Corporation and Novo Laboratories, Inc. Technical information from Miles Laboratories on their Cellulase Tv Concentrate indicates it is an industrial product, not intended for food use. The lowest current price is $20.00/lb. in 100 lb. drum, FOB Clifton, NJ.

ACID SOLVENT PROCESS

Overview

In 1977, a Purdue University group, headed by Dr. George Tsao, achieved a breakthrough with a biomass treatment process that permits recovery of almost 100 percent of the cellulose. The Purdue/Tsao effort directs itself to the refractory nature of native cellulose to enzymatic or mild acid treatment. This resistance to treatment had heretofore limited the yield of glucose. The approach to this problem taken by Dr. Tsao has been to treat the cellulosic material with any one of a number of solvents in such a way as to break down the crystallinity of the cellulose and remove the protective cover of the lignin. After this treatment the cellulose is easily hydrolyzed with either acid or enzyme and the hydrolyzate yield approaches quantitative.

The cellulosic material to be processed, be it wood or other such materials, is pretreated by grinding or chipping to prepare it for easy handling and processing. Using a dilute acid stream recycled from later stages of the process, the pentosans are hydrolyzed to pentoses. These new soluble solids, the "pentose sugars" fraction, are separated from the remaining insoluble ligno-cellulose complex, neutralized and stored ready for further processing into finished fermentation products, such as food and fodder Torula yeast. In preparation for the solvation step the insoluble residue is dried to about 10% moisture in a low pH condition which reputedly aids the subsequent processing. The dried residue is intimately mixed with concentrated (70-85%) sulfuric acid (recovered from subsequent operations) which "dissolves" the cellulose. The cellulose is precipated out by the addition of methanol. The cellulose at this stage is amorphous and is easily depolymerized by acid or enzyme to glucose and other fermentable sugars. To keep the economics of this process within reasonable bounds it is necessary to have good recovery of both the sulfuric acid and the methanol. To attain these recoveries the process is designed to minimize losses and maximize separation and recycle of these materials. It is necessary to control the various operations so that concentration levels are maintained at certain key steps in the process to both balance out the flows and achieve the critical yields.

Although this process had been developed only at bench scale, in 1978 Arthur G. McKee Engineering Company carried out a preliminary engineering and cost analyses of the process which will be briefly outlined herein.[20] The engineering effort on the McKee study was applied only to the basic Tsao Process of conversion of ligno-cellulose to pentose, hexose, and lignin fractions. The lignin is used as a fuel in the power plant. In the McKee preliminary engineering study, the plant was sized to produce a dextrose feed stock for 25 million gallons per year of 190 proof ethanol. Since a large volume of pentoses are produced in such a plant, the optimum size must consider very carefully the economics of the potential product mix dictated by the market place. The alcohol volume above sets the wood waste input to the plant at about 600,000 dry tons per year. The resulting direct capital cost estimate is given on Table 5 and manufacturing cost estimate on Table 6.

Table 5
DIRECT CAPITAL COST ESTIMATE
Purdue/Tsao Process

	$ Million	% Dir. Cap.
Feed Stock Preparation	3.2	7.8
Pentosan Hydrolysis	10.0	24.3
Dehydration	10.8	26.3
Cellulose Solvation	6.6	16.1
Hexosan Hydrolysis (Acid)	2.5	6.3
Lignin Separation	1.4	3.4
Chemicals Storage	.9	2.2
Acid/Alcohol Recovery	5.6	13.6
TOTAL DIRECT CAPITAL	41.1	100.0
Engineering & Construction	6.2	
Contingency	6.2	
Start Up 2.5 Working Capital (2 month mat'l @ cost)	3.0	
TOTAL CAPITAL INVESTMENT	59.0	

Source: Reference 20

Table 6
MANUFACTURING COSTS

	$1,000	¢/lb.F.S.*	%
Raw Materials	$21,080	2.39	53.2
Utilities	7,620	0.87	19.3
Other Variable Costs	3,893	0.44	9.8
Factory Overhead	1,680	0.19	4.2
Depreciation	5,339	0.61	13.5
TOTAL TRANSFER COSTS	$39,621	4.50	100.0

* F.S. is fermentable sugars.

Source: Reference 20

As can be seen the major contribution to these costs are the raw materials. Seventy-eight percent (78%) of the raw materials cost is due to the cost of the corn stover which is priced at $30 per dry ton. However, only about 80% of this price is charged into raw materials as the balance was charged to fuel as contribution of the lignin to the utilities costs. A ten dollar per day-ton change in raw material costs will change the cost per pound of sugars by 0.7¢.

The balance of raw materials costs is distributed among the cost for makeup sulfuric acid and methanol and for lime used to neutralize the acidic sugar streams before storage. The makeup methanol is estimated at 1% of the flow to the recovery system. Even at this low estimate the contribution to the transfer cost is 0.2¢ per pound. The loss of methanol during process or the need for a bleed system to purge impurities can have a significant effect on the economic viability of this process.

There is not enough lignin to supply all of the fuel requirements of this process so it is used to fire the steam generating boiler which needs to have a small supplement of other fuel. The two large residue dryers require other fuel exclusively. Co-generation of fuel was used with a net cost for the resulting steam and electricity of $1.50 per million Btu's. Since the utility cost represent 20% of the total transfer costs, energy conservation in the final design of such a facility should be given considerable attention.

Conclusion

Although the McKee engineering design is based on preliminary bench scale work for the purposes of capital investment and manufacturing costs, the results obtained appear reasonable. At the present time substantial pilot-plant operations are underway on the process at the Purdue University Laboratory of Renewable Resources Engineering (LORRE). Fifty workers are involved in cuurent process development activities, according to a recent telephone conversation with Dr. M. R. Ladisch, a principal engineer of the Purdue LORRE group.

Proprietary pilot-plant process development effort is underway at Purdue University on this process. The BEI attempt to obtain new, up-to-date technical process data and equipment information was not successful since it was learned that would require a secrecy agreement with the Purdue University's Division of Patents and Copyrights because it is proprietary and secret. The Director of the Division is John R. Nesbitt, Patent Attorney. Several attempts were made to contact him, but they were all unsuccessful. Consequently, this process is considered to be unavailable at this time.

COMPARATIVE ANALYSIS

According to the Mitre Corporation's analysis of conversion technologies for manufacturing selected wood-derived energy products,[8] their summary of conclusions related to ethanol from wood were as follows:

> "The technology required for fuel grade ethanol is cellulose hydrolysis and fermentation. Fermentation technology is well-known, widely-used and well developed. Industrial experience is significant for dilute sulfuric acid as the hydrolytic agent.
>
> From the National Energy Supply standpoint, no further research and development activity is required and the current state of the art can be employed for the dilute-acid wood hydrolysis process to be used to provide ethanol supplies for blending with gasoline.
>
> Scope of recommended research and development activities include: assessment of market potential and pricing for by-products of hydrolysis and fermentation; effects of lignin to economics of a large scale plant, compilation of progress and technical data on new acid hydrolysis technologies to establish a large plant design for comparison purposes."

For a comparison of the costs of sugar produced by acid and enzymatic hydrolyses the published costs by Wilke of LBL and Grethlein of Dartmount are given in Table 7. The major differences are that the enzymatic hydrolysis requires about twice the fixed capital of the acid hydrolysis and it produces about 100 ton/day less glucose than the acid hydrolysis.[13] Although the plants capacity of 885 ton/day is the same for the three plants in this comparison, Design I uses a nominal 30% pulp slurry in the plug flow reactor and Design II uses a nominal 10% slurry. The schematic flow diagram for Design I is on Figure 2. In both cases the reactor is assumed to be a plug-flow, isothermal reactor with a residence time of 0.19 min. at 230°C (446°F). The acid concentration is 1% by weight sulfuric acid.

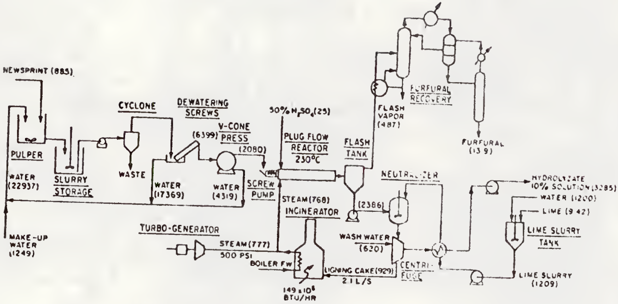

Fig. 2. Process flow sheet for acid hydrolysis. Design I 30% slurry. Material flow in (ton/day)

Table 7

COMPARISON OF DESIGNS I AND II UNIT COSTS WITH ENZYMATIC HYDROLYSIS, INPUT TO ALL PLANTS
885 TON/DAY NEWSPRINT

	Design I	Design II	Enzymatic
Labot related cost	0.167	0.165	0.274
Capital related cost	1.426	1.285	3.558
Raw material cost	0.157	1.788	0.835
Electricity cost	--	0.212	0.538
Total	1.75 ¢/lb.	2.45 ¢/lb.	5.205
Comparison			
Reactor slurry, %	30	10	--
Glucose production rate (ton/day)	327	336	238
Total fixed capital	13,760,000	12,580,000	23,380,000
Percent glucose in hydrolysis (%)	10	10	4

Costs given are for January, 1976.
Source: Reference 13

The characteristics of the three acid hydrolysis and one enzyme hydrolysis processes being evaluated on this project are briefly outlined on Table 8. The comparative evaluation of three modern processes on Table 8 are on Table 9, for the categories of engineering, economics, environmental effects and net energy. The indicated BEI evaluation judgements have a conceptual basis only. They are not based on a directly comparable preliminary design and economic analysis of each process, which would be used if the processes were more directly competitive at the current state of the act.

Table 8

PROCESSES FOR WOOD HYDROLYSIS

	Main Hydrolysis Conditions					
Name	**Medium**	**Temp.**	**Time**	**Yield**	**Sugar Conc.**	**Status**
		(^oC)	(hr.)	(% Theo.)	(wt. %)	
Scholler	1% H_2SO_4	190	24	50	4	Several WW II Plants
Madison	1% H_2SO_4	190	3	52	6	Demo Plants in 1946 and 1
LBL-Natick	enzymes	50	48	33	3	Bench and pilot-plant
Purdue/Tsao	70-85% H_2SO_4	125	--	97	20	Proprietory pilot-plant

Table 9
COMPARATIVE EVALUATION AND RANK

	Acid Hydrolysis	Enzymes Hydrolysis	Acid Solvent
Engineering			
Industrial	9	1	0
Pilot-Plant	4	5	4
Laboratory	6	5	4
	19	11	8
Economics			
Equipment	9	6	6
Corrosion	2	5	3
Reactants	9	2	3
Process	7	3	3
Investment/gal.	7	8	4
	34	24	19
Environmental Effects			
Water	8	7	6
Air	8	8	7
Solid Waste	4	7	3
	20	22	16
Net Energy			
Energy Recycle	6	7	3
Product	6	8	3
	12	15	6
Total	84	72	49
RANK	1	2	3

NOTE: Maximum possible comparative evaluation factor per sub-item in each category is 10; the minimum is 0.

RECOMMENDATIONS

Based on the previous Technology Assessment project and the Phase I engineering research of this project, BEI hereby recommends that the following process be identified as the most appropriate and suitable for the proposed wood waste to FGE production plant in Thompson Falls, MT:

> Dilute Sulfuric Acid Hydrolysis, with plug-flow, isothermal reactor for pretreatment and hemicellulose hydrolysis and the improved Madison process for hydrolysis of ligno-cellulose.

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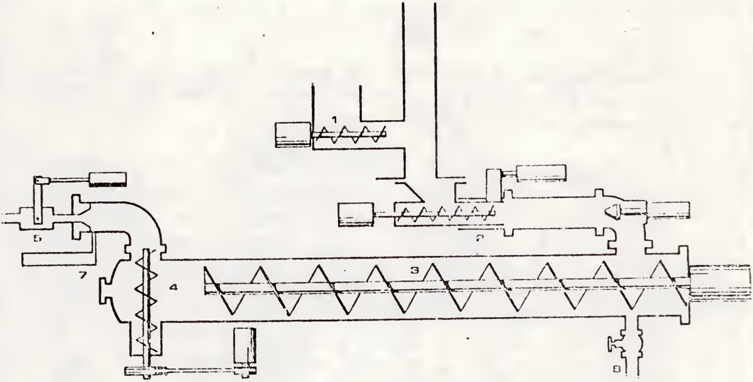
PROPOSED PROCESS TECHNOLOGY

Of the various technological advances which have been made in biomass treatment in recent years, the most relevant to economical ethanol production from wood and crop residues appears to be the new autohydrolysis-extraction process. In the autohydrolysis-extraction process, wood is separated into it's three main components: cellulose, hemicellulose and lignin.

In the selected, modified dilute acid hydrolysis process herein proposed, the wood chips would be pre-treated by autohydrolysis. In autohydrolysis the chips, with initial moisture of 50%, would be heated with 250 psi steam to 400°F (205°C) and held at this temperature for 17 minutes. This time-temperature treatment results in formation of volatiles, water-soluble hemicellulose and alcohol or alkali-soluble lignin from the wood chips. After separation of the volatiles, the hemicellulose and C_5 sugars, about 75% of the original wood substance remains as fibrous ligno-cellulose.

Continuous autohydrolysis would be carried out in a commercially feasible, available reactor designed by Stake Technology from Ottawa, Canada. Currently Stake Technology digesters are in commercial operation at several locations at capacities up to 12,000 dry lbs/hr. They are being used for the continuous processing of wood chips, straws, sugar cane baggase, etc. to economically produce high quality feedstuff for ruminant livestock, such as cattle or sheep. With the Stake Technology process, over 85% of the cellulose is made available for digestion by the bacteria in a cow's stomach. On a directly comparable basis, over 85% of the cellulose would be made available for acid or enzymatic hydrolysis to produce fermentable sugars for yeast fermentation.

A typical Stake Technology reactor has a horizontal tube about 10 inches in diameter and 8 feet long enclosing a helical screw conveyor (see Figure 4). It is fed continuously by a plug-forming helix at one end, and discharged for a few seconds of each minute at the other end. Steam is admitted at about 250 psi pressure near the feed end, and the reaction



MAIN SYSTEM COMPONENTS

1- METERING FEED SCREW
2- PLUG FEEDER
3 - STEAM TUBE & PROPELLING SCREW
4- DISCHARGE SCREW
5- EXPANSION CONTROL VALVE
6 - DISCHARGE TO PRODUCT STORAGE
7- NITROGEN ADDITION SYSTEM
8 - FROM STEAM GENERATOR

Figure 4

STAKE TECHNOLOGY AUTOHYDROLYSIS SYSTEM

temperature rises to the desired level almost instantaneously. The discharge through an orifice at atmospheric pressure is sufficient to completely disintegrate the chips to a very fine pulp.

Through autohydrolysis, the chemical substance of the wood will be separated into three portions: the hemicelluloses in the autohydrolysis liquor, the lignin in the ethanol (or caustic) solvent and the alpha-cellulose in the residue. This pre-acid hydrolysis treatment of wood greatly improves its economical utilization potential as a source of chemicals, energy and food. For example, the hemicellulose solution may be used as a source of xylose, furfural or xylitol, or it may be aerobically fermented to single cell protein in the form of yeast. The alpha cellulose may be used as ruminan feedstuff, or it may be acid or enzymatically hydrolyzed to glucose for fermentation to ethanol and yeast. The lignin may be used as a fuel for steam production or as a source of polyphenols.

The wood pulp portions that result from the Stake autohydrolysis process are produced without any chemical addition, with limited energy in the form of steam, and with very little, almost negligible mechanical energy. The resulting fibrillation and fractionation of the wood chips to alpha cellulose after autohydrolysis has been shown at the University of Toronto, Ontario, Canada to be very economical and energy efficient as the the pretreatment preparation of wood for hydrolysis to fermentable sugars.

Following the hemicellulose liquor separation, the lignin and alpha-cellulose remain intermixed. However, the lignin fraction would be separated by dissolving it in an ethanol solution and filtering the resulting solution away from the remaining alpha-cellulose. The principal advantages of this type of isolation of the lignin from alpha-cellulose prior to acid hydrolysis and fermentation are as follows:

(a) Increased surface area accessibility of cellulose.
(b) Reduced reactor volume for hydrolysis and fermentation (higher throughout or lower capital costs).
(c) Removal of toxic lignin degradation products.

(d) Possibility for recycling alpha-cellulose during acid hydroloysis leading to effective conversion levels of 80-85% sugars from cellulose, as proposed by Georgia Institute of Technology (GIT).

(e) Isolation of a "pristine" lignin by-product with high value-added commercial potential.

Fermentation by Torula Yeast

Torula utilis, a strain of wild yeast, which was identified at the Forest Products Laboratory to utilize 90 to 95% of the reducing sugar when grown on wood hydrolyzate, has been used for the ethanolic fermentation of wood hydrolyzates. Several transfers of the yeast from a completed fermentation to new sugar were required before the ethanol fermentations were as rapid and the amount of ethanol produced was as high as that obtained with S. cerevisiae. Pentose sugars do not appear to be used in the alcoholic fermentation with Torula utilis, but small amounts may be being utilized to grow yeast during or after the alcoholic fermentation is complete. Pilot-plant fermentations in batch and continuous tests indicated that Torula utilis is suitable for ethanolic fermentations and is to be preferred for the fermentation of wood hydrolyzates because of its greater resistance to the inhibiting substances present. It easily maintains sufficient growth in wood hydrolyzates to replace yeast lost in the process and to provide rapid fermentation rates. The yield of ethanol from a Douglas Fir wood hydrolyzate containing 5% reducing sugar was about 90% of theoretical.

The Forest Products Laboratory has used Torula utilis yeast for wood hydrolyzate fermentation to ethanol and yeast (single cell protein). Brelsford developed the required fermentation substrate and aerobic fermentation process conditions and demonstrated a two-hour exponential growth-rate of Candida utilius yeast on barley starch hydrolyzate at pilot-plant scale at Montana State University in 1964.

CONCEPTUAL ECONOMIC ANALYSIS

The Madison Process

In 1975, Raphael Katzen Associates, Consulting Engineers carried out a study of the economics of producing chemicals from wood waste. For the hydrolysis of wood waste to provide fermentation sugars for ethanol production, the dilute acid hydrolysis (Madison) process was selected since it was the only one available that had been used on a commercial, though limited scale.

The RKA plant design centers around the Madison dilute sulfuric acid process developed by the USDA Forest Products Laboratory in 1944-45, which is a semi-continuous process. When a mixture of 25% bark and 75% wood was used instead of wood only, ethanol yield dropped from 65 to 49 gallon per oven dry ton (ODT). Basic design information for this system was taken from the pilot plant data of FPL and pilot-plant development work carried out at TVA. An adjusted investment estimate for 2 and 5 million gal/yr. FGE production has been prepared by BEI and is given on Table 7.

In RKA's selling price or delivered price calculation of ethanol, they included costs for fixed expenses, raw materials, labor, overhead, chemicals, and profit. Fixed costs were based on an allowance of 8% for depreciation, 4% for maintenance, and 2% for local taxes and insurance.

A by-product credit was derived from the sale of furfural and pentoses. It was assumed crude furfural could be sold at 20¢/lb. In July, 1980, market price for furfural was 50¢/lb., which would be equivalent to 27¢/lb selling price based on their assumptions. Pentose sugars can be used to make furfural at about 50% yield or 13.5¢/lb. current selling price value comparison. Profit was based on 30% ROI, equivalent to 15% after taxes.

Table 7

INVESTMENT ESTIMATE
MADISON PROCESS-WOOD WASTE ETHANOL PLANT
(Adjusted from RKA's 25 mm GPY)

Description	Investment ($1000)	
Capacity, FGE gal/yr.	2 MM*	5 MM
Wood Hydrolysis	3,800	6,500
Fermentation	600	1,000
Distillation	800	1,400
Sugar Concentration	1,600	2,700
Sub-Total	7,000	12,000
Steam & Electrical Generation	3,400	6,000
Site Development	400	600
Engineering Fee	1,100	2,000
Estimate Sub-Total	12,000	21,000
Contingency - 25%	3,000	5,000
Working Capital - 25%	800	1,000
Total Investment	$15,800	$27,000
Investment per GPY ratio	$7.90:1	$5.40

* MM = million

Based on the RKA assumed prices for wood waste at $40/ODT, the following selling prices were given or derived by BEI:

Capacity MM GPY*	Selling Price $/gal FGE
100	1.50
50	2.00
5	2.80
2	3.40

* MM GPY = million gallons per year

The GIT Process

The Georgia Institute of Technology Process is a dilute acid hydrolysis process which represents a major breakthrough, technically and economically, in the conversion of cellulosic materials to ethanol. The conceptual and detailed engineering design of the process was developed under contract to the U.S. Department of Energy. A pilot plant is targeted for contruction in 1980 on the campus of the Georgia Institute of Technology.

The GIT Process is based on a unique combination of existing technologies most of which have been substantially demonstrated commercially. Following a detailed survey of alternate processes, it was concluded and stated that the GIT Process was nearer to economic commercialization than any other cellulose-to-alcohol process under development in the United States. A schematic diagram of a 1000 ODT/day GIT process ethanol plant is shown on Figure 5.

The GIT Process provides the following significant advantages over other competitive technologies for the conversion of wood to ethanol:

(1) In contrast to other dilute acid hydrolysis processes, the GIT Process is expected to provide an increase in sugar production up to 85% vs. 55% for other processes (e.g., the Madison Process).

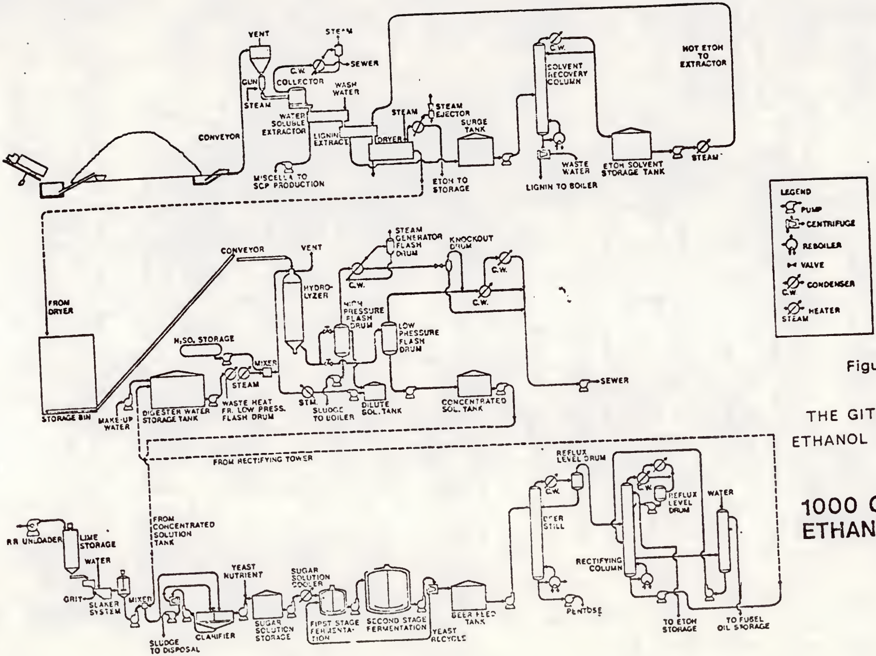


Figure 5

THE GIT PROCESS
ETHANOL FROM WO

1000 ODT/DA
ETHANOL PL

(2) Like other dilute acid hydrolysis processes, the GIT Process is superior economically to concentrated acid hydrolysis processes which depend on costly and grossly inefficient acid recovery system.

(3) The GIT Process will produce sugars from cellulose in yields equivalent to those projected for enzymatic hydrolysis (for which efficient enzymes still need to be developed) but without the tremendously costly need for an associated enzyme production facility.

(4) The GIT Process will convert cellulose to sugars in productive times of an order of magnitude difference from enzymatic hydrolysis for the same yields.

(5) The GIT Process consists of unit operations which are commercially available and largely proven.

The GIT Process achieves these improvements by the critical discovery that cellulose, when separated from the lignin and hemicellulose components of wood, may be converted in a plug flow reactor (PFR), employing cellulose recycling, with conversion to 80%, as contrasted with limiting conversions of 55% in conventional dilute acid hydrolysis processes.

In order to achieve these conditions of productivity, a unique feature of the GIT Process is a pretreatment section which employs "steam explosion" to separate the lignin from the cellulose and hemicellulose in the wood. By simply solvent extraction, using ethanol, the lignin is rapidly extracted in solution in a matter of minutes and at low pressures and temperatues. This feature represents a dramatic improvement in productivity over so-called "organic solvent pulping" which is being commercialized by the pulp and paper industry. While the economic analysis performed on the GIT Process has not taken credit for lignin, except as a process fuel, it is expected that this "pristine" lignin will provide an additional high-value-added co-product if marketed as a chemical feedstock.

The critical combination of the acid hydrolysis delignification and hydrolysis stages in the GIT Process, therefore, afford the following advantages:

(1) Higher sugar yields

(2) Higher throughput in the hydrolysis reactor or a lower capital investment in a hydrolysis reactor (smaller size required)

(3) Elimination of toxic lignin products from carry-over to the fermentation stage

(4) A fuel or high-value-added co-product

A preliminary economic analysis of a 1000 oven-dry ton per day 20 mm GPY FG commercial-scale GIT Process facility indicated that a 95% ethanol product would have a U.S. selling price of $1.69/gallon, which compared favorably with the then current selling price of $1.67/gallon for ethanol produced from grain. By chemical engineering economic adjustments, BEI prepared a rough estimate of GIT ethanol selling prices at smaller scales, as follows:

Capacity MM GPY	Selling Price $/gal.
20	1.69
10	1.95
5	2.26
2	2.74

The Proposed Autohydrolysis Acid-Hydrolysis Process

On the basis of the available autohydrolysis and acid-hydrolysis process technology information, BEI has prepared conceptual design estimates of costs associated with the processing of wood waste to produce FGE. The proposed processing stages include:

autohydrolysis -- ethanol extraction -- acid hydrolysis -- fermentation -- distillation.

The capacity of these fuel grade ethanol (FGE) production plants is 2.4 MM and 6 MM gal/yr. of FGE. The estimates are based on economic adjustments of 10 MM gal/yr. plant economic estimates. The investment estimates are on Table 8 and the operating cost estimate are on Table 9. These rough estimates are based upon a technical paper by the University of Toronto, Ontario, Canada and one by the Georgia Institute of Technology.

Table 8

CONCEPTUAL INVESTMENT ESTIMATE
AUTOHYDROLYSIS - DILUTE ACID HYDROLYSIS ETHANOL PLANT

(Adjusted from 24 MM gal/yr)

Description	Investment ($1000)	
Capacity, FGE gal/yr.	2.4 MM	6 MM
(Wood Handling, ODT/day)*	(100)	(250)
Feedstock Receiving & Storage	300	700
Pretreatment & Solvent Recovery	2,300	5,200
Hydrolysis	800	1,800
Fermentation	800	1,700
Distillation	300	700
Sub-Total Equipment	4,500	10,100
Land, buildings & improvements	1,800	3,100
Engineering & construction	1,200	2,000
Contingency (20%)	1,500	3,000
Fixed Capital Investment	9,000	18,200
Working Capital	700	1,900
Total Capital Investment	9,700	20,100
Plant Investment to gal/yr ratio	$3.75:1	$3.03:1

* ODT = oven dry ton

Table 9

CONCEPTUAL OPERATING COST ESTIMATE

(Adjusted from 24 MM gal/yr)

	Annual Cost ($1,000)	
Capacity, FGE gal/yr.	2.4 MM	6 MM
Item		
Wood, $30/ODT	1,000	2,500
Caustic Soda	300	800
Sulfuric Acid	500	1,200
Fermentation Chemicals	100	200
Packaging and Distribution		
Sub-Total, variable costs	1,900	1,900
Utilities	200	500
Labor	500	1,200
Maintenance	400	700
Other	200	600
Sub-Total, fixed costs	1,300	3,000
Annual Operating Costs, Total	3,200	7,700
Production Costs, FGE (w/o by-product credit, financing or taxes)	$1.33/gal.	$1.28/gal.

Table 10

CONCEPTUAL ECONOMIC ANALYSIS
WOOD WASTE TO FUEL ALCOHOL AND YEAST
INVESTMENT AND MANUFACTURING COSTS

	Fuel Alcohol Production	
	2.4 mgyr*	6 mgyr
	--------------($ million)--------------	
Investment		
Plant Facilities	7.2	15.1
Site Improvement	1.8	3.1
Total	9.0	18.2
Cost of Manufacturing	------------($ million/yr.)------------	
Raw Materials, $30/ODT	1.0	2.5
Denaturants and Chemicals	0.9	2.2
Labor and Supervision	0.5	1.2
Utilities	0.2	0.5
Maintenance	0.4	0.7
Depreciation (10-yr straight line)	0.7	1.6
Miscellaneous	0.2	0.6
Total manufacturing cost	3.9	9.3
Cost of Financing		
80% of Capital Investment @ 12% interest	0.9	1.9
Total Cost of Manufacturing & Financing	4.8	11.2

* mgyr = million gallons per year

Table 11

CONCEPTUAL ECONOMIC ANALYSIS
WOOD WASTE TO FUEL ALCOHOL AND YEAST
PROFIT (BEFORE TAXES)
2.4 million gallons per year

	Selling Price	
	$2.00/gal.	$2.25/gal.
	($ million)	
Investment		
Plant and Improvements	9.0	9.0
Working Capital (15% of Sales)	0.7	0.7
Total	9.7	9.7
	($ million/yr.)	
Sales Income		
Fuel Alcohol, absolute, denatured	4.8	5.4
Fodder Yeast, $600/ton	0.7	0.7
Total	5.5	6.1
Costs		
Cost of Manufacturing	4.8	4.8
General Administration	0.2	0.2
Total	5.0	5.2
Profit, (before taxes)	0.5	0.9

Table 12

CONCEPTUAL ECONOMIC ANALYSIS
WOOD WASTE TO FUEL ALCOHOL AND YEAST
RETURN ON INVESTMENT

20% Investment Credit, Cashflow & Payout
2.4 million gallons per year

	Selling Price	
	$2.00/gal.	$2.25/gal.
	($ million/yr.)	
YEAR 1		
Profit, before taxes	0.50	0.90
Income tax (48%)	-0.24	-0.43
Sub-Total	0.26	0.47
Investment Credit (20%)	+0.24	+0.43
Net Profit	0.50	0.90
YEARS 2, 3 and 4		
Profit, before taxes	0.50	0.90
Income tax (48%)	-0.24	-0.43
Sub-Total	0.26	0.47
Investment Credit	+0.24	+0.43
Net Profit	0.50	0.90
YEARS 5 thru 7		
Profit, before taxes	0.50	0.90
Income taxes (48%)	-0.24	-0.43
Sub-Total	0.26	0.47
Investment Credit	+0.24	—
Net Profit	0.50	0.47

Table 12

CONCEPTUAL ECONOMIC ANALYSIS
WOOD WASTE TO FUEL ALCOHOL AND YEAST

20% Investment Credit, Cashflow & Payout

2.4 million gallons per year

(Continued)

	Selling Price	
	$2.00/gal.	$2.25/gal.
	($ million/yr.)	
FIRST SEVEN YEARS		
Average Annual Profit	0.5	0.7
Add Depreciation	0.7	0.7
Average Cash Flow/Year	1.2	1.4
RETURN ON INVESTMENT		
(average, first 7 years)	12.4%	14.4%
PAYBACK YEARS	8.1 yrs.	6.9 yrs.

Table 13

CONCEPTUAL ECONOMIC ANALYSIS
WOOD WASTE TO FUEL ALCOHOL AND YEAST
PROFIT (BEFORE TAXES)
6 million gallons per year

	Selling Price	
	$2.00/gal.	$2.25/gal.
	($ million)	
Investment		
Plant and Improvements	18.2	18.2
Working Capital (15% of Sales)	1.8	2.0
Total	20.0	20.2
	($ million/yr.)	
Sales Income		
Fuel Alcohol, absolute, denatured	12.0	13.5
Fodder Yeast, $500/ton	1.8	1.8
Total	13.8	15.3
Costs		
Cost of Manufacturing	11.2	11.2
General Administration	0.4	0.5
Total	11.6	11.7
Profit, (before taxes)	2.2	3.6

Table 14

CONCEPTUAL ECONOMIC ANALYSIS
WOOD WASTE TO FUEL ALCOHOL AND YEAST
RETURN ON INVESTMENT

20% Investment Credit, Cashflow & Payout
6 million gallons per year

	Selling Price	
	$2.00/gal.	$2.25/gal.
	($ million/yr.)	
YEARS 1 and 2		
Profit, before taxes	2.2	3.6
Income tax (48%)	-1.1	-1.7
Sub-Total	1.1	1.9
Investment Credit	+1.1	+1.5
Net Profit	2.2	3.4
YEAR 3		
Profit, before taxes	2.2	3.6
Income tax (48%)	-1.1	-1.7
Sub-Total	1.1	1.9
Investment Credit	+0.8	
Net Profit	1.9	1.9
YEARS 4 and 5		
Profit, before taxes	2.2	3.6
Income tax (48%)	-1.1	-1.7
Sub-Total	1.1	1.9
Investment Credit		
Net Profit	1.1	1.9

Table 14

CONCEPTUAL ECONOMIC ANALYSIS
WOOD WASTE TO FUEL ALCOHOL AND YEAST
RETURN ON INVESTMENT

20% Investment Credit, Cashflow & Payout
6 million gallons per year
(Continued)

	Selling Price	
	$2.00/gal.	$2.25/gal.
	($ million/yr.)	
FIRST FIVE YEARS		
Average Annual Profit	1.7	2.5
Add Depreciation	1.6	1.6
Average Cash Flow/Year	3.3	4.1
RETURN ON INVESTMENT		
(average, first 5 years)	16.5%	20.3%
PAYBACK YEARS	6.1 yrs.	4.9 yrs.

ECONOMIC ANALYSIS SUMMARY

The summary of the conceptual economic analysis is given in Table 15. The Cash Flow data does include net profit with allowable investment tax credits for the initial ten year period, but does not include depreciated cash flow.

The Discounted Cash Flow Rate of Return (DCFROR) is for the initial ten year period. The indicated DCFROR is the rate of return that the particular cash flow would allow the annual cash flow to amortize the particular equity investment and also pay the indicated ROR on the unamortized balance each year. Polls of industry presently indicate the DCFROR is the number one economic evaluation decision method used by more than 90% of the industrial companies that use a formal economic evaluation procedure to evaluate the economic potential of investments. For the 2.4 MM gal/yr. production plant with a capital investment of $9.7 million, 20% equity would be $1.94 million. The stockholders in a sub-chapter S corporation could receive tax-free, investment tax credit sheltered dividends for 7 and 4 years for FGE selling price of $2.00/gal. and $2.25/gal. respectively. After the investment tax credit was depleted the corporation should change from sub-chapter S and then the net profit and dividends would be after taxes paid by the corporation.

It should be understood that the indicated DCFROR would clearly allow the individual stockholders to borrow their equity investment funds at an interest rate less than that indicated and the balance would be profit.

Table 15

SUMMARY OF CONCEPTUAL ECONOMIC ANALYSIS
FUEL ALCOHOL FROM WOOD WASTE IN THOMPSON FALLS, MONTANA

				CASH FLOW				
FGE		FGE Selling		w/ITC		w/o ITC*		DCFROR**
Capacity	Investment	Price	Equity	$MM/year	Years	$MM/year	Years	-10 Years
MM gal/yr.	$ Million	$/gal.	%					%
2.4	9.7	2.00	10	1.2	7	0.26	3	125
2.4	9.7	2.00	20	1.2	7	0.26	3	60
2.4	9.7	2.00	30	1.2	7	0.26	3	35
2.4	9.7	2.25	10	1.4	4	0.47	6	140
2.4	9.7	2.25	20	1.4	4	0.47	6	60
2.4	9.7	2.25	30	1.4	4	0.47	6	30
6	20.1	2.00	10	2.1	3	1.10	7	98
6	20.1	2.00	20	2.1	3	1.10	7	43
6	20.1	2.00	30	2.1	3	1.10	7	24
6	20.1	2.25	10	3.4	2	1.9	8	160
6	20.1	2.25	20	3.4	2	1.9	8	72
6	20.1	2.25	30	3.4	2	1.9	8	44

* ITC = Investment Tax Credit

DCFROR = Discounted Cash Flow Rate of Return

CONCLUSIONS AND RECOMMENDATIONS

From the Summary of Conceptual Economic Analysis (Table 15), it is clear that if 10%, 20% or 30% equity were required and available, the economic feasibility of the project, at 2.4 MM & 6 MM gal/yr. FGE capacity would probably have good potential to exist.

The indicated factory door selling prices of \$2.00/gal. and \$2.25/gal. of FGE does include the principal and interest amortization payments as indicated on Table 10.

At the present time FGE produced and sold in Montana is allowed a 70¢/gal. State tax credit in addition to the 40¢/gal. Federal tax credit. Consequently, it can be seen that the net cost to FGE-petroleum distributors would be about \$2.00 - \$1.10 = \$0.90/gal. or \$2.25 - \$1.10 = \$1.15/gal. for the FGE. At this net cost, Montana produced FGE would currently be attractive and offer good future profit potential in the face of the upcoming increases in petroleum fuel prices.

CONCEPTUAL ENGINEERING PLAN
and
ECONOMIC REVIEW

PROCESS TECHNOLOGY

Wood consists of two basic constituents, carbohydrate and lignin. In wood technology, the carbohydrate is referred to as holocellulose, which consists of cellulose and hemicellulose, both polysaccharides. A breakdown of these fractions in softwood and hardwood is given in Table 1.[25]

By means of either acid hydrolysis of hogged or chipped wood or enzymatic hydrolysis of pulverized wood, the carbohydrates present in wood can be converted into sugars. Sugars generated by hydrolysis of the carbohydrates can be processed into products such as:

a. Molasses-type animal feed
b. Yeast (torula or candida strain)
c. Polyols (glycols etc.)
d. Ethanol

The lignin residue from the acid hydrolysis of wood can be utilized as a furnace fuel or converted into phenols. Technology is under development in the U.S. toward the use of lignin as a polyphenolic chemical raw material.

Sulfuric Acid In Montana

Sulfuric acid is commercially available in industrial quantities from the two Montana non-ferris metal smelters of the Anaconda Company and ASARCO, Inc. The ASARCO smelter in Helena, MT, offers chemical grade, virgin acid 93%, 66° Baume for sale in bulk at $58/ton in tank trucks delivered.(1980) They also offer an agricultural grade 93%, 66° Baume at $16/ton FOB the plant in East Helena. For biomass hydrolysis and yeast fermentation, the agricultural grade may not be satisfactory because of possible toxicity to the yeast. The chemical grade would undoubtedly be chemically pure and entirely satisfactory.

The Scholler Process

The first Scholler process plant was built in Germany in 1934 and recovered about 1,000 pounds of sugars from a ton of dry waste wood; sufficient to make about 50 to 60 gallons of ethanol or about 500 pounds of

Table 1

POTENTIAL SUGARS AND ETHANOL FROM WOOD

Wood		Ton Softwood (1)		Ton Hardwood (1)	
Carbohydrate (2)		Pounds	Percent	Pounds	Percent
Cellulose		954	47.7	1070	53.5
Hemicellulose		486	24.3	466	23.3
Carbohydrate		1440	72.0	1536	76.8
Lignin (3)		560	28.0	464	23.2
		2000	100.0	2000	100.0
Sugars					
Hexoses (4)		1124	85.4	1061	74.6
Pentoses (5)		192	14.6	361	25.4
		1316	100.0	1422	100.0
			65.8 (6)		71.1 (6)
Ethanol By Fermentation					
Theoretical (7)		605		571	
Practical (8)	90%	545		514	
	97%	587		554	
Gal 190° Pr	90%	86.7 gal		81.8 gal	
	97%	93.5 gal		88.2 gal	
Yeast By Fermentation					
Theoretical - Torula (9)		610		710	
Actual (10)		550		640	

(1) Oven Dry Basis
(2) Carbohydrate fraction of wood, called holocellulose, includes cellulose and hemicellulose, both polysaccharides.
(3) Lignin fraction of wood is an aromatic or ring structure.
(4) Hexose or 6 carbon sugars include glucose, fructose, mannose, and galactose.
(5) Pentose or 5 carbon sugars include xylose and arabinose.
(6) Sugar as a percent of wood.
(7) Theoretically 53.8% of a disaccharide sugar can be converted by fermentation into ethanol, the remaining 46.2% passing out of system as carbon dioxide.
(8) Best practice results in a conversion of 83 to 92% of sugar to ethanol, with no recycle of yeast; with recycle of yeast, conversion is 96-98%.
(9) Torula yeast is capable of utilizing both 5 and 6 carbon sugars. This yeast contains 50% protein. It can be used as an animal feed.
(10) Expected yield is 90% of theoretical.

dry fodder yeast containing 50% protein. Steel hydrolyzers, 45 feet high and 8 feet in diameter, were charged with 10 to 12 long tons of sawdust and other wood wastes under low steam pressure.[10] The hydrolyzers were lined with acid resistant brick. After the contents were preheated to 265 F., a 0.8% solution of sulfuric acid was introduced at the top and forced through the wood under 35 p.s.i. pressure. Sugar solution was withdrawn at the bottom. The water-to-wood ratio was 12 to 1. After neutralizing, the wort (hydrolyzate) was filtered and was then ready for yeast fermentation into ethanol or for growing yeast into a fodder yeast product. In each hydrolyzer there was a residue of about 6,000 pounds of lignin (600 pounds per ton of wood). This entire cycle required about 24 hours, each acid batch remaining in the cylinder from 45 to 90 minutes.

Three Scholler plants were built in Germany: at Tornesch, in 1934, capacity 25 tons of wood per day; at Holzminden, in 1937, capacity 60 tons of wood per day; and at Dessau, in 1937, capacity 60 tons of wood daily. Other plants were built at Ems, Switzerland, and in Korea. The relatively new Ems, Switzerland plant (probably the only Scholler plant operating in 1952) was modernized further after WW II so that operation cycles would be less than half as long as those used by the Germans; thus the capacity of this plant was double the original 60 tons per day capacity.

The Madison Process

Because of the need for a nonfood source of sugar for the production of ethanol during World War II, the Office of Production Research and Development of the U.S. War Production Board in 1943 instituted an investigation into the hydrolysis of wood at the U.S.D.A. Forest Products Laboratory in Madison, Wisconsin.[22]

Using the short-cycle, acid-hydrolysis procedure, sugar concentrations of 4 to 5.5 percent were obtained by using total water to wood ratio of 8 to 1. The yields of 95 percent ethanol based on the wood input were realized.[29]

Douglas-fir with varying amounts of bark was hydrolyzed to determine the effect of bark on the yield of sugar.[20] Bark which contained 26.4 percent potential sugar gave only 18 percent sugar on hydrolysis while bark-free wood with 67.5 percent potential sugar gave 49 to 51 percent sugar. Chipped slabs contained 34.6 percent bark yielded 38.7 percent sugar.

In the United States in 1946, a commercial-scale processing plant using 220 tons of dry wood waste daily, and based upon the Madison process, was designed and erected in Springfield, Oregon. It's purpose was to supply the infant synthetic rubber industry during World War II.[1] The Madison process provided significant improvement over the Scholler process. Introduction of acid and removal of sugar solution was continuous and required 4 to 5 hours. Lignin, after being blown into a cyclone, was pressed to a moisture content of 50% and then used as furnace fuel for the boiler.[25]

The GIT Process

The Georgia Institute of Technology (GIT) Process is a unique, dilute-acid hydrolysis process developed in 1979 which represents a major breakthrough, technically and economically, for the industrial conversion of ligno-cellulosic biomass to fuel ethanol.[42] The conceptual and detailed engineering design of the GIT process was developed under contract to the U. S. Department of Energy.[34] A DOE financed process development unit was constructed in 1980 on the campus of the Georgia Institute of Technology, Atlanta, Georgia.

The GIT Process is based on a unique combination of existing technologies most of which have been substantially demonstrated commercially. Following a detailed survey of alternative processes, it was concluded and stated that the GIT Process was ready for economic commercialization.

The GIT Process achieves substantial yield and conversion improvements by the critical discovery that cellulose, when separated from the lignin and hemicellulose components of wood can be converted to fermentable sugars in a continuous plug-flow-reactor (PFR), employing cellulose recycling, with conversion yields to 80%, as contrasted with the limited conversions of 55% in the conventional Madison-type semi-continuous dilute-acid hydrolysis processes.

A unique feature of the GIT Process is a pretreatment section which employs "steam explosion" to separate the lignin from the cellulose and hemicellulose in the wood. By simple solvent extraction (after steam explosion) using ethanol, the lignin is rapidly extracted in solution in a matter of minutes and at low pressures and temperatures. While the economic analysis performed on the GIT Process has not taken credit for lignin, except as a process fuel, it is expected that this "pristine" lignin would provide an additional high-value-added co-product when marketed as a chemical raw material.[38]

Continuous Autohydrolysis

Of the various technological advances which have been developed and demonstrated for biomass conversion to liquid fuels in recent years, the most relevant for economical, industrial ethanol production from wood and crop residues is the new "autohydrolysis-lignin extraction process." In this process, wood is separated into it's three main components: cellulose, hemicellulose and lignin.[48]

In the modified dilute-acid hydrolysis process herein proposed, the wood chips would be pre-treated by autohydrolysis. The wood chips, with a moisture content of 50%, would be heated with 400 psig steam to 440°F (227°C) and held at this temperature for several minutes. This time-temperature treatment of the wood results in the formation of volatiles, water-soluble hemicellulose, alcohol-or alkali-soluble lignin and delignified cellulose.[49]

Continuous autohydrolysis can be carried out in a commercially feasible, available reactor designed by Stake Technology, Ltd. of Ottawa, Canada. Currently Stake Technology reactors are in commercial operation at several U.S. locations at capacities up to 12,000 dry lbs/hr.[47] They are being used for the continuous processing of wood chips, crop residues, sugar cane baggase, etc. to economically produce high quality fodder for ruminant livestock, such as cattle or sheep. With the Stake Technology autohydrolysis process, over 85% of the cellulose is made available for digestion by the bacteria in a cow's stomach. On a directly comparable basis, over 85% of the cellulose would be made available for acid or enzymatic hydrolysis to produce fermentable sugars for yeast fermentation.[48]

Through autohydrolysis, the chemical substance of the wood are disrupted and may be separated into three portions: the hemicelluloses in the autohydrolysis liquor, the lignin by an ethanol (or caustic) solvent extraction and the alpha-cellulose in the residue. This pre-treatment of wood greatly improves its economical utilization potential as a source of chemicals, energy and food. For example, the hemicellulose solution may be used as a source of xylose, furfural or xylitol, or it may be aerobically fermented to single cell protein in the form of Torula or Candida yeast. The alpha cellulose may be used as ruminant feedstuff, or it may be acid (or enzymatically) hydrolyzed to dextrose for yeast fermentation to ethanol and single cell protein (yeast). The lignin may be used as a fuel for steam production at the plant or as a chemical raw material source of polyphenolics.

Dartmouth College Process

A continuous plug-flow reactor has been developed for acid hydrolysis of cellulosic materials at Dartmouth College.[11, 12, 13] A single pass hydrolysis at 464°F (240°C) with 1% acid gave 50 to 57% glucose yield for a slurry concentration of 5 to 13.5% solids. For high xylose recovery, a two-stage hydrolysis is needed, the first stage at low temperature (180-200°C or 190 psia Steam) and the second at high temperature (230-240°C or 425 psia Steam).

Hemicellulose Hydrolysis

When the biomass is considered as a chemical raw material, not simply an energy source, it is possible to recover the hemicellulosic pentose (C_5) and hexose (C_6) sugars and subsequently utilize or hydrolyze the remaining ligno-cellulose for other products. Softwood, such as Douglas fir, contains about 24% hemicellulose, of which 13% is hexosan and 11% pentosan polysaccharides.

An economical manner to selectively recover hemicelluloce-based sugars from wood is with a mild acid, pre-treatment process. Since beta- and gamma- cellulose dissociate 100 times faster than alpha-cellulose, wood can be treated mildly to avoid destruction of the fiber, and for preparation to subsequent acid hydrolysis of ligno-cellulose. A patented process has been developed by a Canadian Company, Silvichem Corporation, Ltd., for a mild treatment which does not allow operating temperatures higher than 135°C to avoid the formation of furfural. Private communications with it's inventor indicate is has been demonstrated, and available for commecial application in the U.S.[15]

Fermentation by Torula Yeast

Torula utilis, a strain of wild yeast, which was identified at the Forest Products Laboratory to utilize 90 to 95% of the reducing sugar when grown on wood hydrolyzate, has been used for the ethanolic fermentation of wood hydrolysates.[20] Several transfers of the Torula yeast from a completed fermentation to new sugar were required before the ethanol fermentations were as rapid and the amount of ethanol produced was as high as that obtained with S. cerevisiae. Pentose sugars do not appear to be used in the alcoholic fermentation with Torula utilis, but may be utilized to grow yeast during or after the alcoholic fermentation is complete. Fermentations in batch and continuous tests indicated that Torula utilis is suitable for efficient ethanolic fermentations and is to be preferred for the fermentation of wood hydrolyzates because of its greater resistance to the inhibiting substances present. The yield of ethanol from a Douglas Fir wood hydrolyzate containing 5% reducing sugar was about 90% of theoretical.[20]

D. L. Brelsford developed the required fermentation substrate and aerobic fermentation process conditions and demonstrated a two-hour mother-daughter-mother, exponential growth-rate of 2 hours for Candida utilis yeast on barley starch hydrolyzate at pilot-plant scale at Montana State University in 1964.[7,8] Candida utilis is practically identical to Torula utilis. The aerobic fermentor which Brelsford used was a Waldhof fermentor with pH, temperature, aeration and rpm control. The Waldhof fermentor was originally developed in Germany in the 1930's for single cell protein (yeast) production from wood hydrolyzates.[20] Waldhof fermentors are currently being used in Wisconsin and throughout the world for this purpose.

THE BEI PROCESS

The basic process modules for the production of fuel grade ethanol from wood waste by way of The BEI Process are illustrated in the preliminary process flow block diagram in Figure 2.

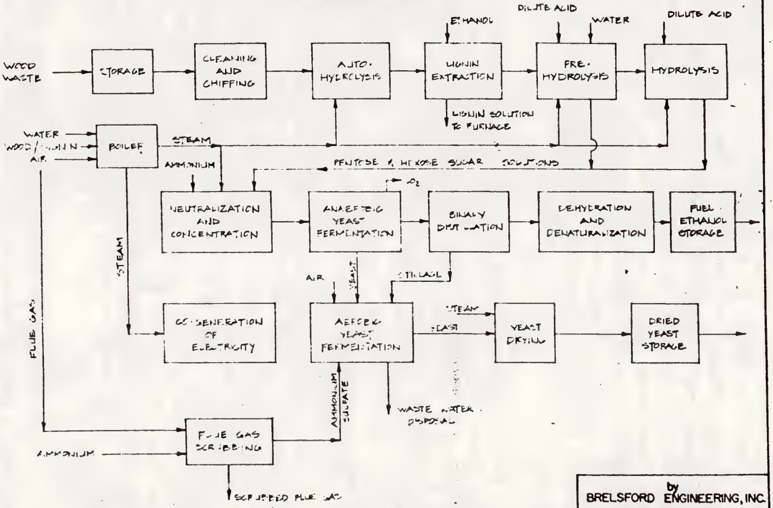
The first stage is called "Autohydrolysis," which means automatic catalysis by naturally present organic acids in the wood. New autohydrolysis reaction ingredients for coniferous woods are being experimentally evaluated by Professor Morris Wayman, Chemical Engineering Department, University of Toronto, Ontario, Canada, in order to improve the effectiveness of autohydrolysis to softwoods. These experiments are currently being run on representative samples of Douglas Fir and Ponderosa Pine wood waste that have been sent from Thompson Falls, Montana. Consulting services are available to BEI from Professor Wayman in the chemical process engineering area . Following autohydrolysis, lignin extraction by dissolution with ethanol is carried out. The resulting softwood lignin products are expected to be physically and chemically lighter and more volatile than would be obtained from hardwoods.

Following the lignin extraction will be the dilute-acid pre-hydrolysis and hydrolysis of the cellulose residue with a plug flow reactor (PFR). The chemical kinetics, dilute acids, temperatures and conditions appropriate for optimum hydrolysis of the cellulose residue will be based on direct communications and consultation with Professor A. O. Converse of Dartmouth College, Hanover, New Hampshire. This process reaction involves a staged, step-down flash of the steam pressure to cool the hydrolyzate and reduce sugar degradation. With adequate steam flashing there are probably economical operating opportunities available for: (1) co-generation of electricity, (2) vacuum fermentation of ethanol and (3) vacuum distillation and dehydration of the fuel grade ethanol.

Since all lignin residue will have been removed, following the cellulose saccharification and the dilute acid neutralization, the fermentable hexose and pentose sugar solutions are clear and ideally appropriate for continuous fermentation and the production of ethanol.

Figure 2

Process Flow Diagram
Fuel Ethanol and Yeast Production
From Wood Waste



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An important point to notice is that the hemicellulose hydrolyzate and pentose sugar solution are combined with the cellulose hydrolyzate and hexose sugar solution after each is appropriately neutralized of acid. This combined solution of hemicellulose and cellulose hydrolyzate, containing all hexose and pentose sugars, are first fed to the continuous anaerobic yeast-ethanol fermentor. Recycle of the yeast cells and a high yeast-cell count in the anaerobic ethanol fermentor will greatly increase the rate, efficiency and quality of continuous ethanol production by yeast fermentation.

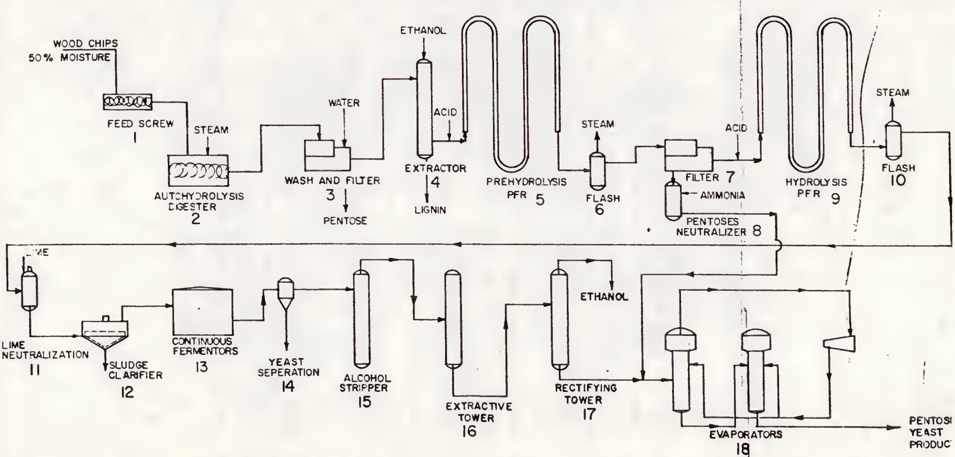
Following anaerobic ethanol fermentation, by Torula utilis or Candida utilis to ethyl alcohol, practically all of the pentose sugars would remain in the stillage at a significant level of concentration. The stripping distillation column will be designed so that the residual ethanol fraction in the bottoms (stillage) will be minimized. The resulting stillage-pentose solution substrate will be the feed stream for the continuous aerobic fermentation for the production of Torula or Candida yeast.

This yeast product will have a 50-55% protein content (dry). It will have resulted from the consumption and reproduction by the yeast cells on the pentose sugars and ammonium ions in the aerobic fermentor. Current U.S. commercial-industrial demonstration of this process in Wisconsin is at 3 hour reproduction cycle time. The industrial application of this process in the U.S. are particularly useful to prevent water pollution from wood sugar liquid effluents of ordinary paper manufacturing plants. This same wood sugar stream can be used to produce ethanol by fermentation as is presently being done commercially by Georgia Pacific Corporation in Bellingham, Washington.

Ammonia will be used to appropriately neutralize the dilute-acid hydrolyzed streams. Consequently it will be available for subsequent consumption as the nitrogen source for yeast (single cell protein) reproduction.

The Process Steps and Schematic Flow Diagram of the BEI process for the dilute acid hydrolysis and yeast fermentation production of ethanol and the pentose solution is given below and shown in Table 2 and Figure 3, respectively.

Figure 3



SCHEMATIC FLOW DIAGRAM-ETHANOL PRODUCTION BY SULFURIC ACID HYDROLYSIS AND FERMENTATION AT THE WOOD WASTE FERMENTATION FACILITY, THOMPSON FALLS, MT

Table 22

PROCESS STEPS
FUEL ETHANOL FROM WOOD WASTE

1. Metering feed screw for 50% moisture wood chips to high pressure.
2. Stake Digester to autohydrolyze hemicellulose and high-pressure steam processing of ligno-cellulosic materials.
3. Hemicellulose autohydrolysate water washed and separated.
4. Delignification by ethanol solvent extraction with recycled ethanol.
5. Hemicellulose pre-hydrolysis Plug Flow Reactor, dilute acid, 130°C.
6. Pre-hydrolysate solution flashed to cool.
7. Cellulose residue separated from Pentose (C_5-type) solution.
8. Neutralysis with Ammonia for Yeast Production.
9. Hydrolysis of Cellulose with dilute acid in Plug Flow Reactor.
10. Hydrolysate solution flashed to cool.
11. Hexose (C_6 type) solution neutralized with ammonia and lime.
12. Calcium sulfate separated.
13. Sugars (C_6) continuous fermentation to ethanol and carbon dioxide.
14. Yeast separated for re-use and yeast product.
15. Ethanol stripped from dilute liquor (beer).
16. Volatiles extraction from ethanol.
17. Ethanol concentrated to 190 proof.
18. Sugars (C_5) concentrated for yeast production fermentation.

"Lake States" Torula Dried Yeast U.S.P. XIX is a commercially-available, primary-grown, nutritional yeast produced in sterile wood sugars media under conditions which permit, and controls which insure, the highest quality food-grade standards. Lake States Yeasts in standard potencies are commercially available to meet all the usual requirements for dried yeast. All types offered by Lake States Division, Monarch Paper Corp. Rhineland, Wisc. are guaranteed to meet or exceed the U.S.P. quality standards.[50]

The process steps and schematic flow diagram for the Lake States yeast production plant follow and are shown in Figure 4.

PROCESS STEPS
DRIED YEAST FROM PENTOSES

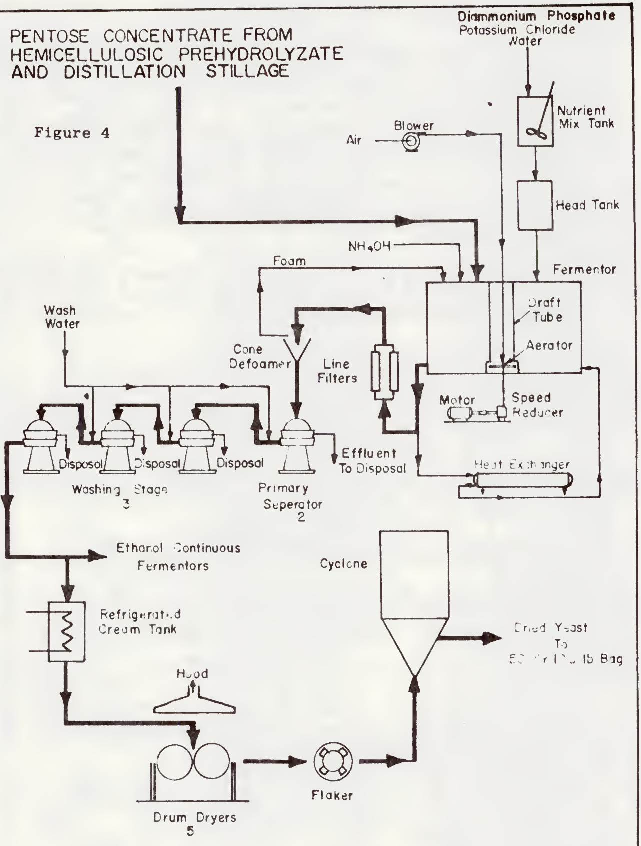
1. Waldhoff Aerobic Fermentation with draft tube for foam control and aeration efficiency.

2. Separation by centrifuge of the yeast cream and spent substrate.

3. Washing of yeast for food quality product.

4. Drum dryers for dried yeast products.

Figure 4



SCHEMATIC FLOW DIAGRAM-PRODUCTION OF FOOD AND FODDER YEAST FROM HEMICELLULOSIC SUGARS AND STILLAGE AT THE WASTE WOOD FERMENTATION FACILITY

COGENERATION

Cogeneration is the generation of power and heat concurrently. The scheme that appears most applicable to the wood waste-yeast fermentation plant is the use of a steam turbine to produce shaft horsepower or electricity. The low-pressure steam from the turbine exhaust is used as a source of process heat instead of being sent to a condenser. By using the energy normally rejected in a condenser, the overall efficiency of the turbine cycle is greatly improved. A great deal of steam at moderately high pressures is required to produce a modest amount of shaft horsepower. So, the process steam demands must be large in order to warrant cogeneration in most cases.

Cogeneration has advantages other than reducing the plant's purchased electrical power. It also can be used for "load shaping." This allows the plant to reduce its purchases electrical load during peak rate periods, thus decreasing peak demand charges.

Table 3 illustrates the amounts of steam required to produce 1 kilowatt hour (kWh) under typical inlet and outlet conditions.

Table 3

STEAM REQUIRED TO PRODUCE ELECTRICITY

Inlet Pressure, Temp.	Outlet Pressure, psig	Pounds/Hr of Steam To Produce 1 kW
150 psig, 366° F	0	38
(50% turbine	10	48
mechanical efficiency)	30	64
400 psig, 650°F	0	17
(70% turbine	10	20
mechanical efficiency)	30	24
	150	60

Source: Reference 52.

Table 3 indicates that 4,800 lb/hr of steam at 150 psig and 366°F (about 150 boiler horsepower) will produce 100 kW of electricity when exhausted at 10 psig. At 400 psig and 650°F, the same 4,800 lb/hr of steam produces 240 kW of electricity when exhausted at 10 psig. Under these same conditions, 20,000 lb/hr would be required to produce 1 megawatt (MW).

PLANT DESIGN BASIS

The dilute acid hydrolysis process which was identified and selected as the basis for this proposed production plant design is the only one available that has been used in sections and sub-systems on a commercial-scale in the U.S. The modern chemical process modifications have been idenfied and are herein proposed by BEI are based upon recent developments and demonstrations in the U.S. DOE Fuels From Biomass Program.

The herein proposed process (The BEI Process) is very similar to "The GIT Process" recently announced and described by O'Neil of Georgia Institute of Technology. The primary differences in the BEI Process include: the use of Stake Technology's continuous "auto-hydrolysis" reactor rather than the GIT semi-batch "steam explosion;" reactor, and the plug flow reactor (PFR) with recycle for the dilute-acid hydrolysis of alpha-cellulose, rather than the fixed-bed reactor in the GIT Process description.[34] The process diagram of the proposed BEI Process has been previously discussed and is shown in Figure 2.

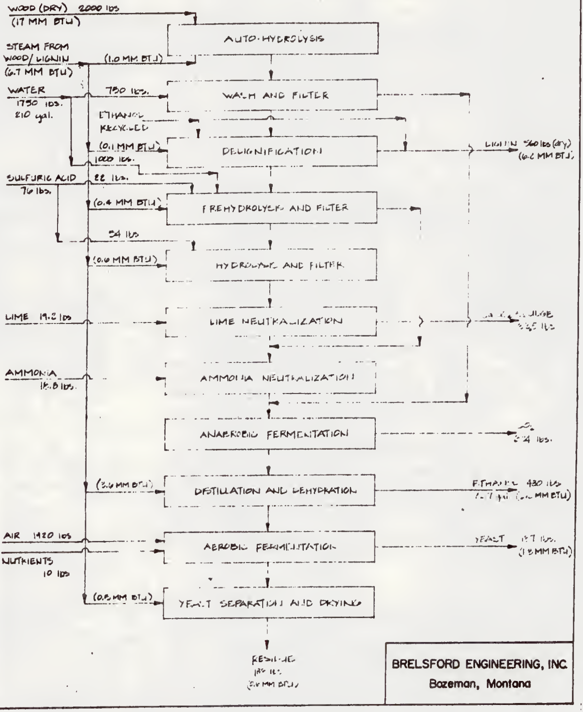
Material and Energy Balance

The diagram of Figure 5 shows the material and energy balance for fuel ethanol and food or fodder yeast production from Douglas Fir wood with 10% bark, through the use of the BEI Process. It will be notices that the balance on this diagram is based on 2000 lbs. of dry wood raw material feed.

Through proper application of the BEI Process, 2000 lbs of wood, on a dry basis, will yield 73 gallons of fuel ethanol, as well as 137 lbs. of food or fodder yeast and 560 lbs. of lignin. The heat of combustion of lignin is 11,100 Btu/lb. Consequently, if the lignin produced is used as furnace fuel for the plant's process steam boiler, at 80% efficiency it would provide 74% of the plant's process steam requirements. The residue, containing hydrolyzed cellulose and other organic materials, has a marginal energy value but may provide up to 10% of the process heat demand as boiler furnace fuel.

Figure 5

MATERIAL and ENERGY FLOW DIAGRAM
FUEL ETHANOL and YEAST from WOOD



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Design Criteria

The preliminary design criteria for the proposed fuel ethanol production plant has been specified by the management of Universal Services Unlimited, Inc. to be as follows:

Plant Capacity 2,400,000 gallons per year motor fuel grade ethanol (FGE), 200° proof.

Plant Location Thompson Falls, Montana.

Feedstock Coniferous Wood Waste (softwood), 10% bark, 100 overn dry tons/day (ODT/D).

Products
- a. 2.4 million gallons per year (MM GPY) ethanol, 200° pr (99.5 wt%), denatured.
- b. Dried Torula or Candida yeast, 10% moisture content.
- c. Lignin, chemical raw-material or furnace fuel quality.
- d. CO_2, atmospheric pressure and battery limits.

Storage
- a. Wood - 30 days feedstock requirement.
- b. Dried Yeast - 10 days production
- c. Ethanol - 30 days production
- d. CO_2 - none
- e. Aldehydes, ketones and fusel oil - disposed by burning in boiler furnace for process heat.

Utilities
- a. Primary Fuel - Lignin and wood waste, with sub-bituminous coal backup.
- b. Water - wells on site, 50°F max.
- c. Electricity - Montana Power Company

Statutory Requirements Must meet all Federal, State and local standards on solid-waste, water and air pollution control; all OSHA standards and all DOT BATF permit requirements.

Operation 24-hours per day, 330 days per year.

Raw Materials and Products

A breakdown of the raw materials and products for the proposed 2.4 MM GPY fuel ethanol production - 100 ODT/D wood waste processing facility is given in Table 4. The overall conversion yield of the carbohydrate fraction of the raw material wood waste to the yeast products, ethanol and yeast, is 76%. This conversion results from conservative application of recently demonstrated and discussed yields and conversion factors, as well as the previously mentioned assumption that the wood waste raw material contains 10% bark on the average.

Table 4

RAW MATERIALS AND PRODUCTS

2.4 MM GPY FUEL ETHANOL FROM WOOD WASTE

	lbs/hr	Tons/day
Raw Materials		
Wood-Douglas Fir (50% H_20)	16,700	200
Sulfuric Acid	300	3.6
Lime	80	1.0
Ammonia	80	1.0
Yeast Nutrients	40	0.5
Water	7,300	87.6
	(14.2 gpm)	(20,000 gpd)
Air	8,000	96.0
	(1,800	cfm)
Products		
Fuel Ethanol	1,820	21.8
	(276 gphr)	(6,600 gpd)
		(2.2 MM GPY)
Dried Yeast (10% H_2O)	578	6.9
		(2,300 TPY)
Lignin	2,340	28.1
Furfural	170	2.0
CO_2	1,770	21.2
Sludge		
Calcium Sulfate	1,400	16.8
Residue	780	9.4

Conceptual Plant Description

The three major inputs to the plant's processing operations are wood, steam, and electricity. Continuous autohydrolysis is carried out on wood chips at 50% moisture with steam at 250 to 400 psig. Lignin which is subjected to the higher pressure steam and resulting temperatures is largely soluble in ethanol. At lower steam pressures and temperatures it is readily soluble in up to 10% sodium hydroxide and subsequently recoverable and isolated by neutralysis by acid.

At 250 psig and 205°C (400°F), the steam requirements for the proposed 100 ODT/D wood waste to ethanol processing plant is 27.9 MM BTU/hr, which would be the output of an 825 bhp (boiler horse power) rated boiler. The furnace fuel requirements for this boiler, utilizing 100% Douglas Fir wood waste at 8,500 BTU/lb, (without lignin as fuel) would be about 2 ton/hr or 50 tons/day. If the lignin produced in the plant is used in the boiler furnace as a fuel rather than sold as a chemical raw material, it would take care of about 74% of the boiler fuel requirements. The heat of combustion of lignin is 11,100 BTU/lb. The addition wood requirement to make up the difference (26%) would be about ½ ton/hr or 13 tons/day of Douglas Fir wood wastes. Consequently, the total wood waste raw material and fuel requirement would be 113 ODT/D.

Continuous autohydrolysis is carried out on the wood chips at 50% moisture with 250 psig steam and 205°C (400°F) temperature in the Stake continuous reactor. In this reactor the naturally occurring organic acis catalyze the depolymerization of the hemicellulose and of the lignin. After a suitable brief retention time, the cellulose residue is blown from the reactor with sudden, almost explosive decompression, which desintergrates the fibre and enhances it's reactivity for further processing.

Hemicellulose is extracted from the auto-hydrolyzed fibre by washing with hot water. A conventional continuous washer or press is quite suitable. Particularly suitable equipment is commercially available which dewaters fiber stock at very high consistency and can thereby make quite concentrated hemicellulose solutions. The solution is thus suitable for conversion to useful products.

Lignin which is subjected to high temperatures, such as 400 psig steam, 238°C (460°F) is largely soluble in ethanol. In the ethanol production plant, the cost of recovery of it would be substantially cheaper than the cost of recovery of the NaOH-H_2SO_4 used in the alternative extraction process. Dilute acid pre-hydrolysis and hydrolysis is multi-staged, relatively fast, inexpensive and well established. After separation of the hydrolysate sugars, the un-hydrolyzed fiber is recycled. The hydrolyzer will be sized for cellulose to sugar hydrolysis conversion of about 25% per pass through the PFR and recycling the separated, unhydrolyzed cellulose along with the new feed cellulose on it's first pass. In this way, glucose yields of about 80% of theoretical are achieved.

For preparation of the yeast fermentation substrate the wood sugars solution will have the pH adjusted by ammonia and lime additions and clarified to remove the precipitated insoluble calcium sulfate. This inorganic compound is chemically identicaly to gypsum, and depending on the quality available from the process operations may have a significant economical market value.

Candida utilis yeast has been demonstrated to be the most suitable yeast for ethanol production and yeast-cell reproduction on wood hydrolysate.[48, 49] This yeast will anaerobically ferment most of the C_6 sugars to ethanol. After the ethanol has been removed by distillation stripping, this yeast will aerobically reproduce rapidly by consuming the wood sugars, nitrogen compounds and oxygen available.

Energy equipment items identifed in the BEI process flow sheet are in full-scale, commercial operation. The autohydrolyzer and hydrolyzer have only a few commercial installations; all other equipment items are common and usually offered by more than one manufacturer.

At this time the identified equipment items and their arrangement in the BEI process have not been assembled commercially for the purpose of producing ethanol and yeast from wood or crop residues. However, the barriers have not been technical, but rather entrepreneurial and political.

The electric power requirement of the proposed plant is conceptually estimated to be about 1000 hp installed, which is equivalent to about 750 KW. As has been indicated in the Cogeneration Section, steam from a high-pressure boiler may be used to drive a turbo electric generator and the exit steam from the turbine can be used for process heat. As previously discussed, the overally process heat requirements for the proposed 100 ODT/D wood waste processing plant would require a high pressure steam boiler rated at about 835 boiler horsepower (bhp) to supply the required 28 MM BTU/hr.

If it is assumed the 28 MM BTU/hr. process steam requirement could be satisfied at an equivalent energy quality of 150 psig steam, then an additional 60 pounds/hr/KW of 400 psig steam would be required to generate the 740 KW electrical power requirements (see Table 3).

This amount of high pressure steam could be supplied by a boiler rated at about 1620 bhp, which would be about twice (1620 ÷ 835 = 1.94:1) the size of the boiler rating requirement for process steam heat only and without cogeneration of the plant's electric power demand.

If the lignin produced from the hydrolysis of 100 ODT/D Douglas Fir wood waste is used for boiler furnace fuel, the additional wood waste for fuel requirement for process heat only would be 13 ODT/D as previously mentioned. If cogeneration of the electrical power demand of the plant is also carried out in the larger 1620 bhp boiler the wood waste fuel requirement in addition to the lignin would be about 60 ODT/D. Consequently, rather than the 113 ODT/D wood waste requirement for raw material and furnace fuel for the 2.4 MM GPY fuel ethanol and yeast plant, the requirement would be increased to 160 ODT/D if the plant were to be designed to cogenerate it's electrical power demand in addition to it's ethanol and yeast production.

ECONOMIC ANALYSIS

On the basis of the available autohydrolysis and acid-hydrolysis process technology information, BEI has prepared conceptual design economic estimates of costs associated with the processing of wood waste to produce FGE and yeast at a small, commercial scale. The proposed processing stages of the proposed BEI Process include:

autohydrolysis -- lignin extraction -- acid hydrolysis -- fermentation -- distillation.

The capacities of this particular proposed fuel grade ethanol (FGE) production plant is 2.4 million gal/yr. of FGE. The economic estimates are based on adjustments from 10 MM and 24 MM gal/yr. FGE from wood waste production plant economic estimates. The estimated investment capital costs are on Table 8 and the estimated operating costs are on Table 9. These preliminary estimates are based upon technical papers by Dr. Wayman, of the University of Toronto, Ontario, Canada and by Dr. O'Neil, Georgia Institute of Technology, Atlanta.

Total annual cost estimates of financing and manufacturing are in Table 10, followed by profit before taxes, Table 11, and return on investment, Table 12. Summary of the overall conceptual economic analysis is given in Table 13. The Cash Flow data does include net profit after allowable Federal and State investment tax credits for the initial ten year period, but does not include depreciation.

The Discounted Cash Flow Rate of Return (DCFROR) is for the initial ten year period. The indicated DCFROR is the rate of return that the particular cash flow would yield and also amortize the particular equity investment. The DCFROR may be assumed to be the minimum desire yield (cost of capital, discount rate). At the indicated DCFROR, the present value of future cash flows generated by the investment will be that rate of return plus giving the full return of the invested capital. Polls of U.S. industry indicate that the DCFROR is the major economic evaluation decision method used by more than 90% of the industrial companies that use a

Table 6

CONCEPTUAL OPERATING COST ESTIMATE

Plant Capacity: 2.4 MM GPY FGE and
230 TPY Yeast

Item	Annual Cost ($1,000)
Wood, $30/ODT	1,140
Lime and Ammonia	140
Sulfuric Acid	130
Fermentation Chemicals	120
Packaging and Distribution	250
Variable costs, sub-total	1,780
Utilities	500
Labor& Supervision	570
Maintenance	380
Other	200
Fixed costs, sub-total	1,650
Annual Operating Costs, Total	3,430
Costs per gallon FGE (w/o by-product credit, financing, taxes, or profit)	$1.43/gal.

Table 7

CONCEPTUAL ECONOMIC ANALYSIS
WOOD WASTE TO FUEL ETHANOL AND YEAST
INVESTMENT AND MANUFACTURING COSTS

Plant Capacity: 2.4 MM GPY FGE and
2300 TPY Yeast

Investments, $1,000	
Plant Facilities	9,600
Site Improvement	1,300
Total	10,900
Cost of Manufacturing, $1,000/yr.	($1,000/yr)
Wood Waste, $30/ODT	1,140
Chemicals	390
Labor and Supervision	570
Utilities	500
Maintenance	380
Depreciation (10-yr straight line)	960
Miscellaneous	450
Total manufacturing cost, $1,000/yr.	4,390
Cost of Financing, 20 yr. Amortization 80% of Capital Investment @ 15% interest ($1,000/yr.)	1,390
Total Cost of Manufacturing & Financing, $1,000/yr.	5,780

* mgyr = million gallons per year

Table 8

CONCEPTUAL ECONOMIC ANALYSIS
WOOD WASTE TO FUEL ALCOHOL AND YEAST
PROFIT (BEFORE TAXES)
Plant Capacity: 2.4 MM GPY FGE and
2300 TPY Yeast

	Selling Price	
	$2.00/gal. FGE	$2.25/gal. FGE
	($1,000)	
Investment		
Plant and Improvements	10,000	10,000
Working Capital (15% of Sales)	960	1,050
Total	10,960	11,050
	($1,000)	
Sales Income		
Fuel Alcohol, absolute, denatured	4,800	5,400
Fodder Yeast, $700/ton	1,610	1,610
Total	6,410	7,010
Costs		
Cost of Manufacturing	5,780	5,780
General Administration	230	230
Total	6,010	6,010
Profit, (before taxes)	400	1,000

Table 9

CONCEPTUAL ECONOMIC ANALYSIS
WOOD WASTE TO FUEL ALCOHOL AND YEAST
RETURN ON INVESTMENT

20% Investment Credit, Cashflow & Payout

	Selling Price	
	$2.00/gal.	$2.25/gal.
	($ 1,000/yr.)	
YEAR 1		
Profit, before taxes	400	1,000
Income tax (48%)	-192	-480
Sub-Total	208	520
Investment Credit (20%)	+192	+480
Net Profit	400	1,000
YEARS 2 thru 4		
Profit, before taxes	400	1,000
Income tax (48%)	-192	-480
Sub-Total	208	520
Investment Credit	+192	+480
Net Profit	400	1,000
YEARS 5 thru 7		
Profit, before taxes	400	1,000
Income taxes (48%)	-192	-480
Sub-Total	208	520
Investment Credit	+192	+27
Net Profit	400	547

Table 10

CONCEPTUAL ECONOMIC ANALYSIS

WOOD WASTE TO FUEL ALCOHOL AND YEAST

20% Investment Credit, Cashflow & Payout

	Selling Price	
	$2.00/gal.	$2.25/gal.
	($ 1,000/yr.)	
FIRST SEVEN YEARS		
Average Annual Net Profit	400	547
Add Depreciation	960	960
Average Net Cash Flow/Year	1,360	1,507
RETURN ON INVESTMENT (average, first 7 years)	12.5%	13.8%
PAYBACK YEARS	8.0 yrs.	7.2 yrs.

Table 11

Conceptual Economic Analysis

Fuel Ethanol and Yeast from Wood Waste
Plant Capacity - 2.4 MM GPY & 2300 TPY Yeast

FGE CAPACITY	INVESTMENT	FGE SELLING PRICE	EQUITY	ANNUAL AVERAGE NET CASH FLOW w/ ITC* $1,000/yr	YEARS	after ITC $1,000/yr	YEARS	DCFROR** 10 YEARS
MM gal/yr	$1,000.	$/gal.	%					%
2.4	10,450	2.00	10	1,260	7	205	3	125
2.4	10,900	2.00	20	1,260	7	208	3	61
2.4	10,900	2.00	30	1,260	7	205	3	37
2.4	10,750	2.25	10	1,507	4	520	6	136
2.4	10,900	2.25	20	1,507	4	520	6	62
2.4	10,900	2.25	30	1,507	4	520	6	37

* ITC = INVESTMENT TAX CREDIT

** DCFROR = DISCOUNTED CASH FLOW RATE OF RETURN

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ENVIRONMENTAL FACTORS

The U.S. Department of Energy's Environmental Development Plan (EDP) for Fuels from Biomass identifies environmental, health, safety and socioeconomic (EHSS) issues to be assessed as the biomass production and conversion technologies advance toward public utilization and commercialization. The USDOE EDP identifies the research needed to resolve these issues and provides a plan for the orderly development of required research. The EDP supports the overall biomass technology development program, as described in USDOE Division of Solar Energy planning documents, by ensuring that EHSS problems are specified in such a way that mitigation and control of potential problems are achieved in a timely manner.

Five key environmental issues that are related to this proposed alternative fuel alcohol from wood waste biomass project, as well as the DOE Fuels from Biomass Program, have been identified in the EDP. Their general nature is briefly outlined as follows:

(1) The large land and water requirements of terrestrial biomass plantations may restrict the development of competing uses of land and water (e.g., food and fiber production) in some regions and cause adverse socioeconomic impacts.

(2) Biomass plantations (both agricultural and silvicultural) have the potential to significantly affect local and regional air and water quality through fugitive dust emissions and sediment loads to waterways.

(3) Removal of silvicultural residues or natural timber total harvesting or clear-cutting schemes reduce the amount of organic and inorganic matter which decaying residues provide to the soil, and thus their harvest may limit future crop or forest growth.

(4) Direct combustion of biomass can, in some cases, emit greater quantities of the air pollutants: nitrogen dioxide, carbon monoxide, and particulates, than from fossil-fuel combustion.

(5) The various thermochemical biomass conversion processes produce small quantities of pollutants, such as hydrogen sulfide and phenols, which can affect air and water quality. In addition, tars and oils are generated which may present in-plant and community health and safety concerns.

These five EHSS areas may be accurately characterized, analyzed and assessed as they particularly relate to the construction and commercial operation of the proposed 2.4 million gallons per year fuel grade ethanol from coniferous wood waste production plant in Thompson Falls, Montana.

Depletion of Soil Organic Content Due to Residue Removal

Recovery of logging and forest residues and total harvesting schemes tend to reduce the generally beneficial, natural replenishment of organic matter that decaying residues provide the soil. Logging residues remaining on open forestland may play a major role in preserving moisture content and protecting the soil from wind and water erosion. However, they also present a particular fire hazzard that can be kindled by natural lighting strikes. Their removal could possibly deplete the organic soil content which aids the internal binding of the soil at the same time it reduces the fire hazzard to the living forest. Environmental impacts associated with silviculture may be indicated by analysis of timber residue harvesting schemes which remove the total or portion of forest residues normally left behind, and reduce the forest fire hazzard in the Lolo National Forest of Western Montana.

Mitigation of soil depletion may involve partial removal of forest residues, as the woody part and not the needles. The percent that can be safely removed is probably significant. The extent to which total or partial forest residue removal could adversely affect soil quality still is undetermined, and is probably forest and logging area specific, as is fire hazzard elimination.

Social and institution impacts of forest biomass energy use primarily arise from production and harvest rather than conversion. For forest biomass applications employing terrestrial vegetation, social/institutional impacts stem largely from the land areas required and the agricultural procedures employed. Consequently, land use impacts, agricultural-forest policies and regulations may be the major focus of institutional impacts from this silvicultural technology. Forest biomass production and harvest also may result in significant competition with fiber markets for available resources, i.e., land, fertilizers, equipment, and water. Institutional regulations would be required to address conflicts during fiber shortages. These regulations may be proposed to prioritize needs in relation to fiber or energy when conflicts in these markets occur from shortages in the future.

Yeast fermentation, which produces ethanol, and bacteria anaerobic digestion, which produces methane, both have similar environmental characteristics. Both process schemes employ micro-organisms in an aqueous medium and both generate a sludge which must be disposed of. Carbon dioxide from anaerobic yeast fermentation-ethanol production may be recovered as a saleable product or wasted to the atmosphere. The residue mixture includes a solution of dissolved potential pollutants and an undissolved portion of inorganic solids. This mixture is generally separated into solid (single cell protein) and aqueous components prior to by-product preparation. Nevertheless, effluents from either process (anaerobic digestion or ethanol fermentation) require similar treatment and may result in similar environmental impacts. Ethanol fermentation as an energy production technology is becoming increasingly significant at the commercial scale. Fermentation of sugars to ethanol from acid hydrolysis of wood and crop residues produces a liquid effluent requiring treatment before disposal. The in-plant treatment can be anaerobic digestion to produce methane bio-fuel and/or aerobic yeast fermentation to produce single cell protein (SCP) in the form of yeast.

In addition to the decrease in water pollution and air pollution by bioconversion of crop residues and wood waste biomass, the production of renewable alternate fuel energy resources to the form of liquid fuel ethanol will result in significant conservation of non-renewable fossil liquid fuels. The possible competition and replacement of synthetic ethanol by fermentation ethanol of biomass also could conserve fossil fuels presently used in the chemical industry.

Bioconversion of agricultural wastes, including wood wastes, logging residues, and crop residues, is a sound, compatible environmental practice in Western Montana with regard to pollution abatement and energy conservation. However, the use of logging and timber residues as the raw material biomass for ethanol and yeast production must be appropriately matched with the recycling of the mineral ash from the steam boiler furnace to the soil for positive mineral fertilization values.

The Occupational Safety and Health Act of 1970 (OSHA) places important responsibilities on design engineers for safety in chemical and biochemical process plants, such as this proposed one, which involves the acid-hydrolysis of wood waste (WW) to produce fuel grade ethanol (FGE) and food and fodder yeast (FFY) in Thompson Falls, Montana. The OSHA standards and regulations refer throughout to the first effort to achieve maximum compliance through the application of engineering principals of design.

In the preliminary design activities of this proposed project, BEI engineers and consulting engineers would look beyond the calculations and drawings, and attempt to realistically anticipate safety related work factors during construction and operation of the facilities. Typical in-plant and off-site hazzards that may occur by accident at a FGE production plant include: explosion of steam boiler from over pressurization, scalding from steam gasket leaks, contact burns from steam lines, ignition of ethanol leaks or fumes, handling of acids/bases and suffocation from carbon dioxide.

The Montana Environmental Index is a compilation and summary of all environmentally related State laws and regulations. The purpose of the index is to assist anyone in acquainting themselves with the State's legal and institutional approach to environmental matters. In the BEI preliminary design phase, the Index would be used as appropriately as necessary to find the particular Revised Codes (status) and Administrative Code (regulations) for complete texts when accuracy is required. This Index will also provide for awareness and understanding of appropriate Federal EHSS rules and regulations, including Federal Clean Air and Federal Water Pollution Control Act.

The Montana Major Facility Siting Act provides for the comprehensive review of the siting and construction of major facilities engaged for the generation, distribution or conversion of energy. The goal is to maintain and improve a clean and healthful environment for future generations, to protect the environmental life support system from degradation, and to prevent the unreasonable depletion of natural resources. Such facilities must receive a certificate of environmental compatibility and public need from the Montana Board of Natural Resources and Conservation. The proposed FGE from WW production facility in Thompson Falls, Montana probably does not come under the jurisdiction of this particular act. However, that situation would be confirmed by BEI at the beginning of the EHSS Task of this project. In order to encourage the conservation of energy and the use of renewable energy sources, tax and other incentives are provided in Montana Legislation.

BEI and environmental consultants would carry out an environmental impact assessment (EIA) including socioeconomic impact of the proposed facility in the Thompson Falls, Mt. area. The EIA report would include local, State, and Federal environmental rules, regulations and guidelines which would be applicable to the proposed facility. Itemization would be made of the environmental-based permits and approvals required for the construction and operation of the FGE production plant. Information and monitoring requirements necessary for each permit application would be addressed, as well as the estimated time and dollar costs for submittal and approval of all permit application. Any control and monitoring requirements certain or likely to be mandated as permit conditions would be itemized and described.

An assessment would be made of the current environment at the selected facility site and the probable level of residual emissions. The needed and necessary environmental information for the siting, construction, and operation of the 2.4 million gal./yr. FGE production plant from wood waste in Thompson Falls, Montana, would be gathered and developed through the use of current state-of-the-art and established equipment and operating techniques.

In 1975 through 1977, Donald L. Brelsford, Principal Engineer of Brelsford Engineering, Inc., (BEI) was the Chief Environmental Engineer, Head of the Environmental Engineering Department and Manager of the Engineering Division of the Montana Energy and MHD Research and Development Institute, Inc., (MERDI) in Butte, Montana. In those positions he was responsible for all aspects of pre-operational baseline monitoring environmental impact assessments related to the DOE MHD Component Development and Integration Test Facility (CDIF) in Butte, Montana. In these positions, he directed, developed and applied several new, innovative approaches to EIA and baseline monitoring. The MERDI engineering and environmental staff, under his direction and supervision, assisted to a major extent on the DOE Task Force that prepared and achieved approval of the DOE Environmental Development Plan of the MHD Program. This work was coordinated by project officers of the Divisions of Environmental & Socioeconomic Programs and Technology Overview, ERDA in Washington, D.C. in September, 1977.

Socioeconomic impact assessment would be made of the Thompson Falls, Mt. area as well as that part of the Flathead Indian Reservation where the timber resource management and utilization is an important factor. Air and water quality data that exists would be gathered and analyzed. In addition, appropriate, necessary additional monitoring would be carried out and correlated to other sites with long-term forecasting data bases.

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CANDIDATE PLANT SITES

CANDIDATE SITES

For a fuel ethanol from wood waste processing plant, the selection of the plant site is not readily reducible to a few major controlling factors. The check list below will be used to evaluate and rank the three candidate sites, as it has been used in the identification of these candidate sites.

Utilities: The site must have adequate water supply, compatible waste disposal opportunities and adequate to electric utility access.

Fuel: Economic availability of bark and log fuel from lumber mills, along with transportation suitability for economic availability of low-sulfur sub-bitumen coal from Montana coal supplies.

Geographical Features: Cost of the site development should not be a significant element of capital expense. In addition, the site should be nearly level, well drained and preferably have soil bearing values in excess of 2000 lbs/sq.ft. Accessibility to good roads and railroad line will be evaluation factor.

Feedstock: Close proximity to feedstock supply: a mill siting or close proximity to area's logging activities. (Within a 150 mile radius).

Environmental: Compatibility to local and state environmental regulations.

Cost: Suitable price range or lease durations.

Three sites, within the Thompson Falls area, have been identified as candidate sites. Discussions with the owners are currently underway. Following is a description of the candidate sites that have been identified.

SITE A

Description: Approximately 88 acres of flat ground with small stand of Ponderosa Pine planted at plantation intervals, 6-15 feet in height. Balance is open field.

Location: Approximately 4 miles east of Thompson Falls, south of and adjacent to Montana Highway No. 200 and north of Burlington Northern Railroad (BN) right-of-way at 2400 feet above sea level (ASL) elevation.

Water & Utilities: There is no water on the property, but could be obtained from a well or by pumping from the Clark Fork River, about 600-800 yards away.

General: Access to this property is good, convenient and year-round. Potential uses are numerous due to convenient transportation routes and facilities. Neighboring properties are being used for commercial, industrial and residential purposes. The county airport is within one mile.

SITE B

Description: Approximately 200 acres of flat ground on two different terrain levels with over 1 mile of Clark Fork River frontage, ground partially covered by open stand of Ponderosa Pine and Western Larch. Balance of ground used as hay meadow.

Location: Approximately 4 miles east of Thompson Falls, south of BNRR right of way and country road at approximately 2400 feet ASL in elevation.

Water and Utilities: There is considerable water available from water rights to the Clark Fork River. There are springs on the eastern portion of the property adjacent to the river. Electricity is available to the property.

General: This property is adjacent to the Sanders County airport and a Sanders County gravel road, less than 1 mile from Montana Highway 200. Access is convenient and year-around. It has potential for number of uses, including an industrial facility.

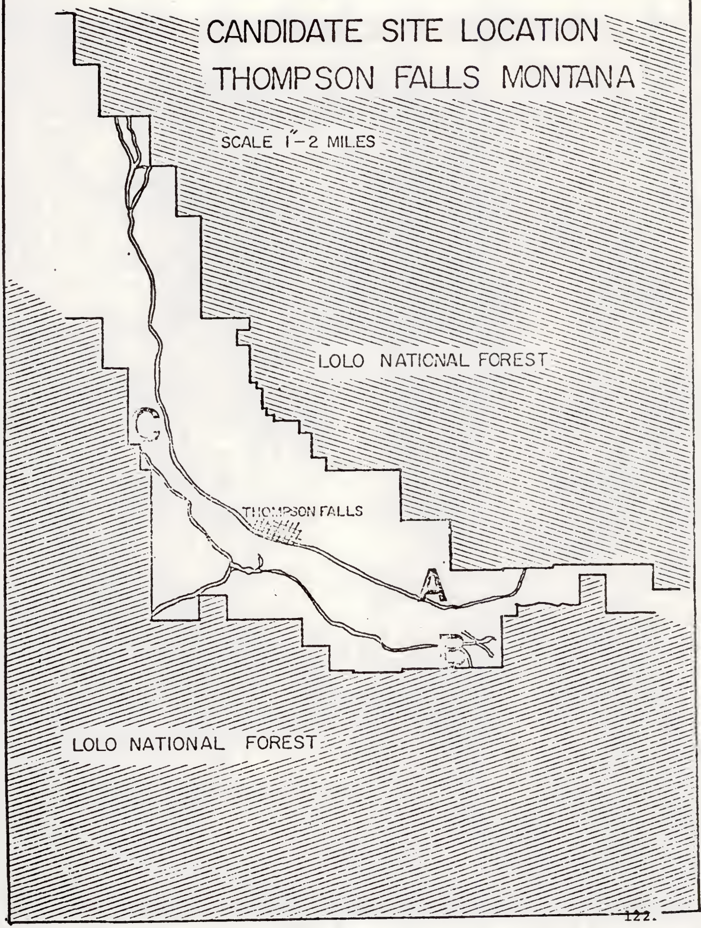
SITE C

Description: Approximately 40 acres of flat forested land on one level approximately 20 feet above the Clark Fork River which borders the property on the east side. A five acre parcel has been and is currently being used as a sanitary land fill for the Thompson Falls area.

Location: Approximately 2 miles north of Thompson Falls on Montana 200. The property is accessible year-around on paved state and county roads. The Burlington Northern Railway runs approximately 1/4 miles from this site.

Water and Utilities: There is currently no power or water on this property, but both are available. Water for industrial use could be pumped from the Clark Fork River.

Figure 6


CANDIDATE SITE LOCATION
THOMPSON FALLS MONTANA
SCALE 1"–2 MILES
LOLO NATIONAL FOREST
C
THOMPSON FALLS
A
B
LOLO NATIONAL FOREST

MARKET STUDY

FUEL ETHANOL

Montana Petroleum Situation

"Gasohol" is the commonly accepted name for a fuel mixture of gasoline and ethyl alcohol or ethanol. Mixed in proportion of 90% gasoline and 10% alcohol, Gasohol can be burned in an internal combustion engine without carburetor modifications. While some modifications are required to run an engine on 100% alcohol fuel, current cars will run on Gasohol without any modifications or loss of performance. Fuel grade alcohol has become established and accepted as an octane additive in Gasohol and as an alternate renewable fuel extender for gasoline and diesel fuel.

Ethanol production can be derived from the hydrolysis, fermentation and distillation of many types of Montana crops, crop residues and wood wastes. The future need and demand of fuel of fuel alcohol in the Montana region is directly related to the current and future supply and price of petroleum fuel products. A recently prepared report by Brelsford Engineering of Bozeman, MT, "Montana Petroleum Situation-1978", provides detailed information related to the potential need and demand for fuel alcohol in Montana and is discussed below.

In 1977, there were seven operating crude oil refineries in Montana. Over the 10 year period from 1968 through 1977, the volume of crude oil refined in Montana increased from 41 million barrels per year to 48.3 million barrels (+17%) with a peak of 51 million barrels reached in 1973. Approximately ninety percent of Montana crude oil refinery capacity is located in and near Billings, Montana as indicated in Table 1.

Montana currently imports from Canada approximately 50% of the crude oil refined in the State. Canadian crude oil is purchased for

Table 1

CRUDE OIL REFINED BY MONTANA REFINERIES - 1977 & 1978

Refinery	Volume (million barrels/yr)		Percentage of Montana (%)	
	1977	1978	1977	1978
Wesco Refining Co. Cutbank, MT	1.5	1.8	3.2	3.8
Kenco Refining Co. Wolf Point, MT	0.9	1.0	1.9	2.1
Phillips Petroleum Co. Great Falls, MT	2.1	2.1	4.4	4.4
Big West Oil Co. Kevin, MT	0.3	--	0.6	--
Farmers Union - Cenex Laurel, MT	12.7	12.9	26.3	27.0
Exxon Company Billings, MT	13.9	14.5	28.9	30.3
Continental Oil Company Billings, MT	16.8	15.5	34.7	32.4
Montana, Total	48.3	47.7	100.0	100.0

Source: Montana Board of Oil and Gas Commission, Annual Review.

refining in Montana on a direct, inter-regional, crude oil exchange basis by the particular U.S. and Canadian oil companies involved. Allowable Canadian crude oil exports without exchange will be cut to zero by 1983.

The annual rate of crude oil production in Montana has declined less than 1% over the twelve year period of 1965-1977, while in Wyoming and North Dakota crude oil production has declined 23.8% and 13.6% respectively. The increase in U.S. crude oil production of 4.8% over this period represents the Alaskan crude oil production increase. The estimates of proven reserves of crude oil in Montana reported in the Montana Department of Natural Resources and Conservation's 1979 Historical Energy Statistics Report indicate a drop in reserves from 240 million barrels in 1970 to 151 million barrels in 1977. The projection is for this decline to continue.

The petroleum situation in Montana was relatively stable in the decade through 1978. However, in 1979 it became apparent that this situation was beginning to change in a negative direction.

The continued importation of Canadian crude oil on a long-term, reliable basis is fundamental to future, good economic conditions in Montana. However, an adequate supply of Canadian crude oil to Montana refineries via exchange is not considered to be probable on a long term basis.

Gasoline consumption in Montana and the neighboring four states during the 1965-1977 period are given in Table 2. From this data it is clear that gasoline consumption increased by about 50% in the Northern Rocky Mountain region in the last decade. Monthly gasoline consumption for 1976 and 1977 in Montana is indicated in Figure 1, and clearly shows the major influence that the summer tourist season in Montana has had on gasoline demand.

Table 2

GASOLINE CONSUMPTION IN THE MONTANA REGION

(Thousand Gallons)

State	1965	1970	1975	1976	1977	1965-1977 % Change
Idaho	321,015	400,735	482,462	520.640	530,225	+65.2%
Montana	327,979	385,762	454,831	499,879	482,003	+47.0% (average +3.4% year
Wyoming	197,524	246,367	319,042	343,229	361,399	+81.3%
North Dakota	347,490	380.564	433.293	452,723	452,771	+30.3%
South Dakota	378,833	420.259	500,414	473,672	489,384	+29.2%
U.S. Total	70,327,125	89,405,263	104,271.433	109,655.206	112,960,215	+60.6%

Source: 1962-1973 American Petroleum Institute.
1974 Federal Highway Administration, Table MF036, April 1976.

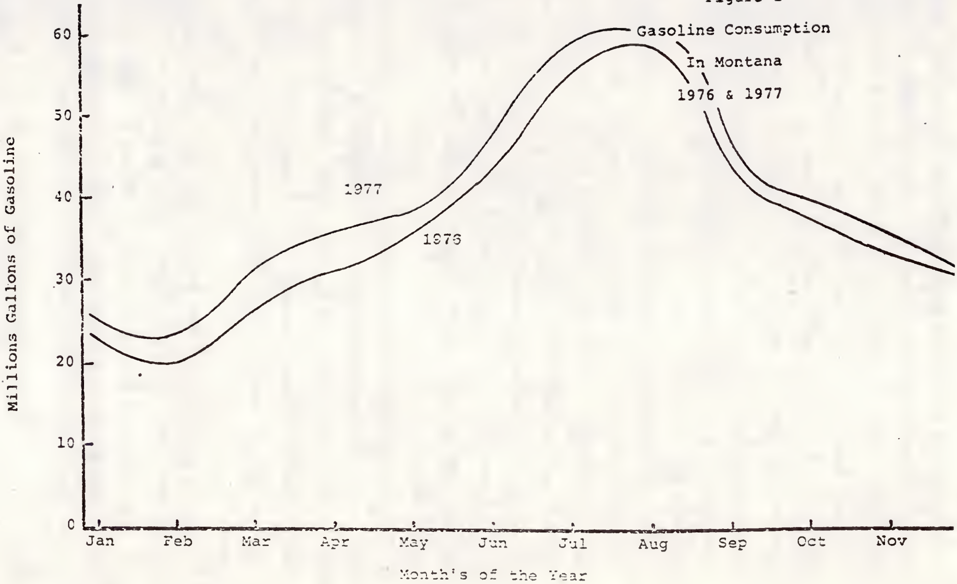


Figure 1
Gasoline Consumption
In Montana
1976 & 1977

Source: Montana Department of Revenue, Mote Fuels Tax Division

During the three year period 1976-1978, motor fuel consumption in Montana increased about 4.9%. The gasoline portion of motor fuel sales showed an increase of 5.7% compared to 8.8% increase for total aviation and jet-fuel sales, as indicated in Table 3. Also in Table 3 is an indication of the gasoline gallonage consumed in 1976 and 1978 for the six major cities of Montana. Bozeman appears to have had the largest increase in gasoline consumption of +37.9% in this 1976-1978 period, followed by Missoula with +22.2%.

Gasoline gallonage consumption may also be reviewed and analyzed according to the seven Montana Crop Reporting Districts with boundaries as indicated in Figure 2. Of these seven districts, the Southwest District, which includes Butte and Bozeman, experienced a +12.7% gasoline consumption increase over the 1976-1978 period. The Northcentral District had a 6.9% decrease in gasoline useage, with the Northeast District a 6.7% decrease, as indicated in Table 4.

In the Montana agriculture sector, the energy requirement per acre for major crops in 1973 was reported in a 1976 Montana Energy Advisory Council Report. The report indicates that dryland barley production required, on the average, 4.4 gallons of gasoline per acre or 1.4 gal/acre of diesel fuel on a comparable basis.

It is widely known that gasoline prices have been steadily rising throughout the past decade. Price increases are related to increased costs of imported oil as well as the increased cost of oil exploration and production. Service station gasoline prices, over the period of 1965-1977, have increased 102.5%.

Table 3

MONTANA MOTOR FUEL CONSUMPTION

Montana	1976	1978	Percentage Change
	(million gallons)		%
Total, Aviation & Jet Fuel	35.4	32.3	+8.8
Total, Exclusive of Aviation & Jet Fuel	482.5	509.8	+5.7
Montana Motor Fuel, Total	517.9	542.10	+4.9
Cities of Montana			
Butte	18.8	18.2	-3.2
Great Falls	54.7	58.3	+6.6
Billings	71.4	73.2	+2.5
Missoula	46.5	56.8	+22.2
Helena	27.6	32.9	+19.2
Bozeman	19.8	27.3	+37.9

Source: Montana Petroleum Association, Montana Gasoline Gallonage Report.

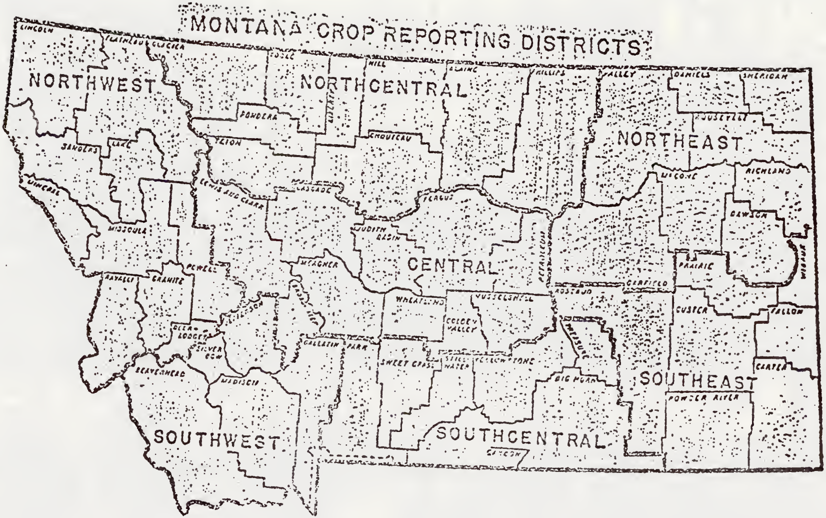


Figure 2: Montana Crop Reporting Districts.

Table 4

GASOLINE CONSUMPTION BY MONTANA CROP REPORTING DISTRICT

	1976	1978	Percent Change
	(million gallons)		%
Northwest	117.0	128.7	+10.0
Northcentral	56.3	52.4	-6.9
Northeast	46.0	42.9	-6.7
Central	110.4	120.1	+8.8
Southwest	58.9	66.4	+12.7
Southcentral	108.4	108.4	0
Southeast	20.9	23.3	+ 11.5
Total	517.9	542.1	+4.7

Source: Montana Petroleum Association, Montana Gasoline Gallonage Report.

Table 5

AVERAGE REGIONAL RETAIL GASOLINE PRICES FOR SELECTED CITIES

	1977		1965-1977 Change	
Average City/State	Total Gasoline Taxes	Service Station Price Including Taxes	Total Gasoline Taxes	Service Station Price Including Taxes
	(cents/gallon)		(%)	(%)
Idaho, Boise	13.50	65.48	+35.0%	+74.9%
Montana, Great Falls	11.84	65.44	+18.4%	+77.3%
Nebraska, Omaha	12.83	66.15	+16.6%	+103.4%
North Dakota, Fargo	11.33	66.40	+13.3%	+105.8%
South Dakota, Huron	12.00	63.87	+20.2%	+87.5%
Wyoming, Cheyenne	11.00	65.75	+10.0%	+82.7%

Source: Platt's Oilgram Price Service. T.A.P., Inc.

During the same period, State and Federal taxes have increased 18.4%. Throughout the Montana region, retail gasoline price increases have been led by North Dakota at 105.8%, followed by Nebraska at 103.4%. In Great Falls, Montana, retail gasoline prices appear to have changed +77.3% over this twelve year period. (See Table 5).

Prices for petroleum products in Montana will increase and probably accelerate as a result of the increased prices for off-shore oil which is needed for exchange for Canadian crude oil imported to Montana from Alberta. The increased cost of domestic U.S. oil exploration and production will also have a direct effect, along with inflation and the recent decontrol of gasoline prices. Petroleum products can be expected to increase steadily in consumer demand unless voluntary and/or mandatory conservation programs are initiated and become effective.

Fuel Ethanol Demand in Montana

For the purposes of this study, the population considered most likely to purchase and handle bulk fuel grade ethanol (FGE) direct from the plant would be the State's Wholesale Petroleum Distributors (WPD).

From a population of 535 WPD, 125 were randomly selected and asked to respond to a survey questionaire. The questionaire contained questions pertaining to the following:

1. WPD current use and demand for FGE
2. WPD future use and demand for FGE
3. Type of FGE products WPD demands

4. Reasons for not distributing FGE products
5. WPD current availability of FGE
6. Current and estimated number of gallons of FGE sold
7. Alternative uses and demands for FGE
8. Montana counties serviced by the WPD

With regard to the State's current use and future demand for FGE, 3.2% of those WPD responding to the questionaire were currently selling FGE products, while 8.8% were planning to sell within the next year and 15.2% within the next five years. Although they were currently making no plans to sell, 17% of the sample stated their demand for FGE would increase in the next five years and 15% were unsure.

All respondents selling or planning to sell FGE were interested in 190-200 proof to be sold as a 10% blend with gasoline. Most of the WPD were planning to blend the gasohol at their own facility.

When asked why they were not now distributing FGE products, several reasons were given. 27% of the sample felt that FGE costs were presently too high, 26% had difficulty in obtaining a regular supply, and 25% gave other reasons. Of this 25%, 34% (10% of the sample) stated that they had no storage and blending facilities equipped to handle bulk FGE and 51% stated there was no demand for it. Another 15% gave miscellaneous reasons such as "We're not convinced that FGE is a practical alternative to gasoline", and "Our suppliers have not yet made it available".

Of those WPD's now selling gasohol, 50% were purchasing bulk 200 proof FGE direct from out of state producers Almarc and Archer Daniels Midland. The other 50% were purchasing direct from their franchise company and unable to identify the manufacturer.

Of those WPD now selling FGE products, 25% stated they were having difficulties obtaining a regular supply.

Only 25% of the sample responded to questions pertaining to the amount of gallons sold and to be sold. For this group 36,000 gallons of FGE will be sold in 1981 and 177,000 in 1986.

When asked about the alternate uses of FGE, none of the WPD surveyed were able to provide alternatives outside it's use as a motor fuel.

To estimate the demand for FGE on a regional and geographic basis, respondents were asked first to identify the counties in which they distribute products, then their "yes" or "no" answers to: Whether they are currently distributing FGE products, whether they are planning to distribute FGE products in the next one and five years or whether they may possibly sell in the next five years, were tabulated on a per county basis. It was determined that the number of positive responses each county received for the various questions would be relatively equal to its demand for FGE.

Since each county did not receive an equal number of times it was served by the various WPD's in the sample (some received much larger numbers than others), the possibility that this would scew the results existed. That is, those counties with the highest number of times served may be more likely to show a higher demand. To check this possible effect, correlation coefficients were calculated for the numbers respective to the times the county was served and it's estimated demand in one year, demand in five years, and possible demand in five years for fuel ethanol. Understanding a direct positive correlation to be 1, the respective coefficients were .08, -.03, and .07, indicating no strong correlations between variables.

Tables 7, 8, and 9 show those counties with the greater demand for fuel ethanol in one and five years.

Conclusions

Based on the results of this study, it would appear that there is a growing demand for FGE in Montana. Although the current number of WPD's selling FGE is low at 3.2% of those surveyed (see Table 6), an increase of 175% is expected in the next year and 375% in the next five years. If those WPD's who anticipate an increased demand in the next five years (17% of the sample) and those who were possibly considering selling ethanol in the next five years (24.8%) reached a decision to sell in year five, the number of WPD selling would increase by 945%.

Another potential increase in the number of WPD selling FGE exists if one considers that 26% of the sample indicated that they were not now selling FGE because they were unable to obtain a regular supply. If this indeed was the only reason they were not now selling and a regular supply were made available, an increase by 712.5% of FGE distributors would occur, when a regular supply became available. Further, 10% of the sample indicated not having suitable storage and blending facilities to handle FGE. Should they become so equipped, another increase of 212.5% would occur.

If the 8.8% of WPD making plans to sell FGE within the next five years follow through and sell it as a 10% Gasohol blend, and assuming that the 1981 consumption of gasoline would be 54 7 million gallons (See Table 2), then it is possible that an increased demand for 4·8 million gallons of FGE could occur. Likewise, if those 15.2% of WPD follow through with their plans to sell ethanol by 1986, then another increase in demand of approximately 9.6 million gallons per year could occur.

If by the year 1986, all the gasoline sold in the state, a potential 630 million gallons (determined by projecting the average yearly increase of 3.4% from 1977 to 1986 - see Table 2), were sold with a 10% blend of FGE then a yearly demand for 62.9 million gallons of FGE would exist.

On a national basis in 1977, nearly 113 billion gallons of gasoline was consumed in the U.S., and by 1986 an estimated 123 billion gallons will be used (based on recent DOE estimate of 1% per annum growth rate of energy demand). This creates a potential national annual demand for approximately 12 billion gallons of FGE by 1986 if all gasoline was supplemented with a 10% addition of FGE.

The likelihood that this demand will be higher exists when consideration is given to such factors as reduction in the amounts of imported oil, reduction in domestic oil production, rapidly increasing prices for petroleum products, plus Federal and State encouragement for the development of the nation's energy resources.

A few rather large companies dominate these state and national markets at this point. But the number of smaller companies is growing as gasohol becomes more popular. Archer Daniels Midland in Illinois and Midwest Solvents in Kansas are mentioned most often as the biggest producers of FGE. According to the National Gasohol Commission, the other major alcohol fuel producers are Georgia Pacific, Publicker, Mar Cam Industries, Milbrew and Amarc. (See Table 10).

Table 12 represents a national summary of those FGE manufacturers expecting to be on line by 1985. In Montana no known manufacturers are now producing FGE, but by the end of 1983 at least nine are expected to be on line with a combined production of 62.2 million gallons. (See Table 11)

The fact that the projected domestic production of FGE (4.4 billion gallons by 1985) falls short of the state and national demands is encouraging enough that further project development is recommended. As a result of an attempt to identify a specific outlet for the proposed plant's 2.4 million gallons per year of FGE, Universal Services received from one group of Montana petroleum distributors a letter of intent stating "As per our phone conversation (we) are interested in negotiating an agreement for the purchase of ethanol produced by your plant at Thompson Falls, Montana. As I indicated to you, we feel that for gasohol to have a steady long term usage it must be marketed at or near the price of unleaded gasoline. Also, as I indicated to you, our group has the capacity to and would be interested in contracting for your total output. Please accept this letter as our intent to negotiate an agreement with you."

TABLE 6

SUMMARY OF 125 OF MONTANA'S WHOLESALE PETROLEUM DISTRIBUTORS INTENT TO SELL FUEL ETHANOL

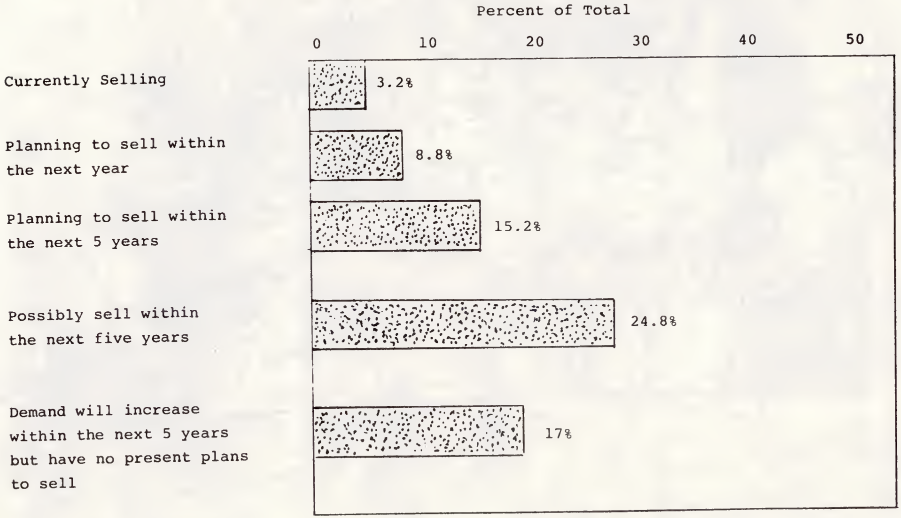
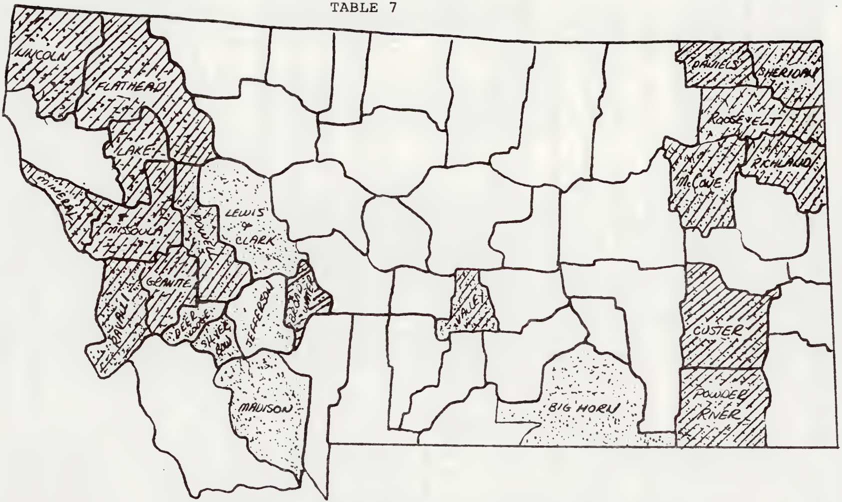


TABLE 7

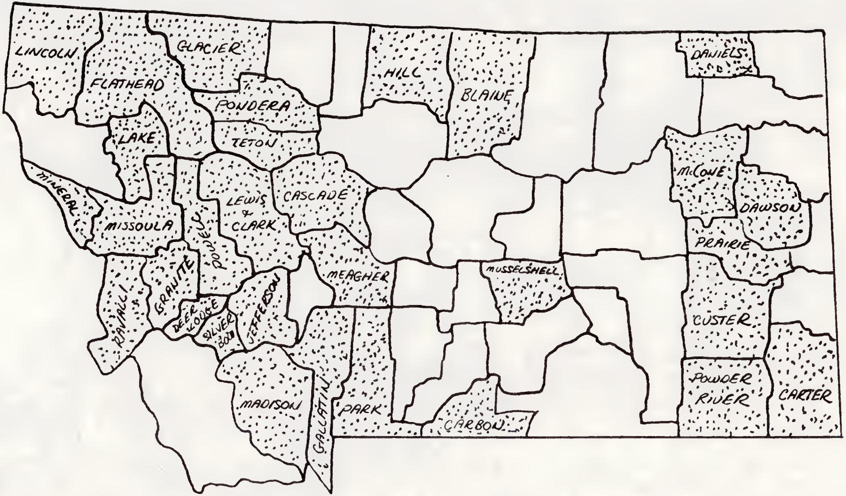


STATE GEOGRAPHIC DEMAND FOR FUEL ETHANOL IN 1981

░ represents those counties in which Fuel Grade Ethanol will be distributed

▨ represents those counties in which Fuel Grade Ethanol is now being distributed

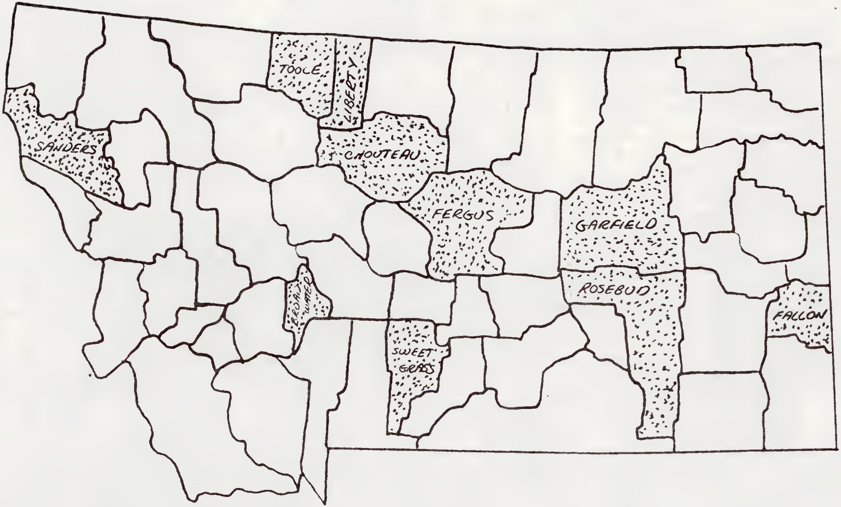
TABLE 8



STATE GEOGRAPHIC DEMAND FOR FUEL ETHANOL IN 1986

▨ Represents those counties in which Fuel Grade Ethanol will be distributed

TABLE 9



ADDITIONAL POTENTIAL STATE GEOGRAPHIC DEMAND FOR FUEL ETHANOL IN 1986

▨ Represents those counties which may distribute Fuel Grade Ethanol

TABLE 10

MAJOR MANUFACTURER'S ALCOHOL FUELS MARKET REPORT

FOR WEEK ENDING MARCH 20, 1981

Company	Price/gallon Week of 3/20/81	Price/gallon Week of 3/13/81	F.O.B.
Archer Daniels Midland	$1.80	$1.80	Decatur, IL
Archer Daniels Midland	1.80	1.80	Elizabeth, NJ
Publicker	1.80	1.80	Philadelphia, PA
Midwest Solvents	1.78½	1.78½	Atchison, KS
Mar-Cam Industries	1.80	1.80	Carteret, NJ
Mar-Cam Industries	1.85	1.85	Panama, FL
Mar-Cam Industries	1.95	1.95	Los Angeles, CA
Mar-Cam Industries	1.80	1.80	Madison, IN
Mar-Cam Industries	1.80	1.80	Texas City, TX
Mar-Cam Industries	1.85	1.85	Tampa, FL
Georgia Pacific	1.78	1.78	Bellingham, WA
Milbrew	1.80	1.81	Juneau, WI
Almarc	1.79	1.79	Bensenville, IL

(Source: Biofuels Report, March 23, 1981)

TABLE 11

PLANNED FUEL PLANTS IN MONTANA

Company	Annual Capacity (thousand gallons)	Primary Feedstock	Primary Heatsource	Production Date
A E Montana	576	Barley	Natural Gas	2/81
AG-NRG, Inc.	1000	Barley	Natural Gas	4/81
Agro-Tech Inc.	4000	Barley	Coal	7/81
Blackfeet Energy	4000	Barley	Coal	12/81
Energy Engineering, Inc	7700	Wheat	Geothermal Energy	1/83
Kevin Development Corp.	1000	Barley	Coal	* 0
Montana Agri-Processors	3000	Barley	Coal	4/82
Sammons (Herb)	40,000	Barley	Coal	3/82
Sun Prairie Energy	1000	Barley	Other	1/82
TOTAL:	62,276			

(Source: U.S. National Alcohol Fuels Commission)

* Production date not available

TABLE 12

PLANNED U.S. PRODUCTION OF FUEL ETHANOL BY 1985

STATE	ANNUAL CAPACITY (gallons)	NUMBER OF COMPANIES
Alabama	51,825	3
Arkansas	65,655	7
Arizona	8480	4
California	236,371	11
Colorado	80,860	13
Delaware	3200	1
Florida	93,800	9
Georgia	41,493	10
Hawaii	25,000	2
Iowa	245,530	18
Idaho	59,800	11
Illinois	263,350	28
Indiana	252,624	21
Kansas	68,569	8
Kentucky	79,060	11
Louisiana	726,949	13
Maryland	39,200	5
Maine	25,000	1
Michigan	117,000	9
Minnesota	113,900	9
Missouri	36,610	4
Mississippi	1500	1

Table 12, continued

STATE	ANNUAL CAPACITY (gallons)	NUMBER OF COMPANIES
Montana	62,276	9
North Carolina	91,576	6
North Dakota	89,750	10
Nebraska	143,525	9
New Hampshire	10,000	1
New Jersey	17,500	2
Nevada	10,000	1
New York	51,788	6
Ohio	124,000	7
Oklahoma	37,960	5
Oregon	46,073	6
Pennsylvania	123,253	5
South Carolina	64,300	7
South Dakota	25,390	6
Tennessee	69,350	6
Texas	276,920	12
Utah	31,750	4
Virginia	259,570	13
Vermont	7900	2
Washington	179,300	8
Wisconsin	54,500	8
West Virginia	1000	1
Wyoming	25,000	3
TOTAL:	4,435,457	

LIGNIN

The proposed facility will produce 9273 tons of relatively pristine lignin per year. For the purpose of this study, the plant's lignin residue was considered to be the major fuel source for its converstion process. (Up to 75% of the facility's energy needs will be supplied by the thermoconversion of the residual lignin)

Although lignin has value as an energy source, it may have even greater value as a chemical feedstock and various other industrial applications.

The chemical nature of lignin has long intrigued scientists with its complexity and potential multiple uses. Until only recently, however, has the western world turned its attention to the development of its varied uses. This is because of at least two reasons: 1) Large quantities of relatively pure lignin have not been available commercially and 2) until recently petro-chemical feedstocks have been in abundant supply providing little motivation and the need to develop alternative chemical feedstocks such as those than can be obtained from lignin.

Never the less, certain types of lignins particularly the lignosulfonates and kraft lignins, by-products of the paper industry, have been developed and marketed successfully.(6)

Sugar-free lignosulfonates from softwoods serve as a starting material to make vanillin, a flavoring for food, ice cream and bakery goods. Although this product has now replaced the natural vanillin essence extracted from vanilla beans, the demand is small. In fact, three manufacturers are able to supply the needs of North America and much of the foreign market. A few other fine organic chemicals used as food preservatives in suntan lotions, or as pharmaceuticals are also made from vanillin or softwood lignins.

Lignosulfonates are readily soluble in water and possess certain detergent-like properties. Just as soaps loosen dirt, lignin solutions can disperse and suspend inorganic particles. This makes them valuable for a number of uses.

One major application is for mud viscosity control during deep oil drilling. The boring head must be slightly lubricated and cooled, otherwise it will either burn away or jam and the powdered rock produced by the drill must be removed from the shaft. A solution of lignosulfonates in water does the job well by forming a stable thin mud that will not coagulate or foam but can ooze out of the hole. Similarly, lignosulfonates also help control the viscosities of particle suspensions in making bricks, tiles or gypsum boards, in grinding and polishing, in spraying pesticides, in distributing carbon black during rubber masterbatching and in textile dying. Another use is in the preparation of smooth clay slips for ceramics - on firing the pieces, the organic lignin simply burns away. Lignin is also said to reduce breakage and chipping of dried, unfired bodies of pottery and porcelain.

Many uses of lignosulfonates and spent sulfite liquor as a binder rely on the ability of these materials to couple smooth dispersion with tackiness. In this capacity, lignin finds outlets in preparing insulation boards, linoleum and floor tile pastes, animal feed pellets (the Food and Drug Administration permits 4 percent), coal dust briquettes, and foundry sand casting forms. It is also used for dust control in ceramic manufacture, synthetic fertilizer production and application, cement clinker milling, and concrete mixing. In concrete mixing, lignosulfonates also reduce the water requirement of the mix through the slurry thinning caused by their dispersant properties. This accelerates setting and can be used to control air entrainment in the concrete. Lignosulfonates are also used as soil stabilizers on soft shoulders or unfinished roads; here, too, they exert considerable dust control.

Lignins are also strong sequestering agents, that is, they enclose certain metal ions and keep them in soluble form. They form soluble complexes readily with iron, calcium, copper, nickel, tin, aluminum, and zinc. This property leads to their use in treatment of poor soils--either to add deficient minerals or to remove detrimental ones--in industrial cleaning compositions, in hard water treatment and in boiler-scale control.

They also find applications in metallurgy. Specific mineral dispersing and depressant effects plus sequestering power make lignosulfonates effective in slime control and in improving separation during tabling or flotation of ores. By counteracting electrode polarization, they are valuable additives for galvanizing baths or in the electrolytic refining or ores. Lignin is also incorporated into the negative electrode coating pastes of lead storage batteries.

The anionic charges (negatively charged ions) in lignosulfonates make them good emulsifying agents or auxiliaries for preparing or stabilizing oil-in-water or wax-in-water emulsions (for example, in polishes and furniture creams or sprays). As wetting agents, they are used in tar or asphalt emulsions or as stabilizers in some emulsion paints.

Lignins are also included in some adhesives. They act as extenders for the phenolic resins used in manufacturing particleboard, nonwoven fiber padding, and molding powders. They are also compounded into polyvinyl alcohol and polyvinyl acetate glues and used for rewettable gummed tapes.

Lignosulfonates also have tanning properties because of their phenolic and sulfonic acid groups. However, being water soluble, their effect is not permanent; they are therefore only used as extenders for vegetable or chrome tannins. This ability to coagulate and precipitate proteins is also exploited in water clarification. Effluent from meat and fish canneries or milk processing processing plants can be advantageously treated with carbohydrate-free lignosulfonates and the protein-rich precipitate deposited then incorporated into animal feeds or protein-based glues. It helps to abate water pollution in certain applications.

Uses of kraft or alkali lignins are not as numberous mainly because they are less soluble in water. Applications similar to those for lignosulfonates (for example, in ceramics and tire manufacturing) are sometimes possible. In addition, kraft lignins are used in some foam fire extinguishers to stabilize the foam and in printing inks for high speed rotary presses. Tables 13 and 14 summarize the lignin products and their variety of uses which have been developed by the Lignin Chemicals Division of the American Can Company. Although these lignin products have been developed from lignosulfonate waste as discussed above, American Can Company is apparently developing new products. These products utilize more pure forms of lignin, such as those derived from the proposed conversion process.

Today's industry relies heavily on fossil based raw materials. Because these materials are dwindling in supply and their costs are increasing, research is becoming more and more interested in developing the technology to utilize renewable organic substances as substitute industrial raw materials. Since lignin constitutes the major underutilized renewable organic substance available on earth exceeded possibly only by urea, scientists have given it a good amount of attention. Scientists in various parts of the world have approached lignin product development from two perspectives as Dr. Glasser at the Virginia Polytechnic Institute discusses below:

> "An evaluation of subject areas of publications in the field of lignin utilization demonstrated that researchers in countries of the Western World look at lignin mainly as material suited for direct use without prior modification, or as a raw material for feed stock chemicals by degradation. In contrast, research in eastern countries and Japan seems to focus more on applications that use lignin in its polymeric state following modifications by grafting and the like. The latter, obviously, requires a more sophisticated technology, aims at higher quality products, and makes better use of the inherent properties of the polyphenol. Among eight subject areas in research on lignin utilization, studies dealing with resin and and adhesive applications continue to hold the number one post, followed now by dispersants; in the 1950-62 period, the second place was still occupied by research on degradation

> products. Other topics that have declined during the past 20 years are lignin isolation and purification, tanning properties and ion exchangers; in contrast, research on lignin's potential use for agricultural purposes and for rubber additives has steadily gained more importance. It is thus evident that scientists in the lignin field, particularly in the Eastern World countries and in Japan, are rapidly learning about the physical and chemical properties of high molecular weight lignin byproducts, and that they explore uses of lignin that draw benefit from these properties. An intensified research effort on the part of western countries seems to be necessary if lignin is to become an important raw material for future chemical industries in the West."

As Dr. Glasser recommends, Western research has begun to turn its interest to the development of higher quality lignin products. For example, Battelle Columbus Laboratories have developed techniques by which high value industrial chemical compounds can be obtained from biomass feedstocks. From soluble lignin epoxy resin, epoxy novalac and polycarbonate resins can be produced. These chemicals can be used as molding resins and adhesives, and have the potential to displace petroleum derived chemicals such as bio-phenol A which is currently being sold for 62¢ per pound. Battelle lists four distinct advantages of soluble lignins which make them attractive for further product development. They are:

1. Easily produced from more than one source of biomass
2. Difficult to obtain from petroleum feedstock
3. A minimal loss of fixed carbons and oxygen for obtaining this chemical from biomass
4. Capable of being an intermediate for a variety of high value products (2)

The application of lignins with the greatest near-term commercial potential is the sulfonation of biomass lignins for the production of products like those that American Can has developed and discussed above. Long term potentials include utilization of highly condensed biomass lignins as fillers and matrices and production of phenolic resins from softwood lignin. Such products could demand prices upwards to 30¢ per pound. (8)

As research proceeds, other valuable uses are expected to be discovered, for lignin holds considerable potential as a very versatile industrial raw material.

Lignin, however, will require more market development but should be considered as a future co-product with the production of alcohol and torula yeast.

TABLE 13

AMERICAN CAN COMPANY - LIGNIN PRODUCTS

INDUSTRIAL CLEANERS

Marasperse, Maracell, Kelig and **Maracarb** are used effectively in industrial cleaners to disperse dirt particles, prolonging bath life by inhibiting viscosity increase. This enhances lubricant removal, leaving a free-rinsing character to the cleaned metal surface. They sequester metal ions, too. American Can lignins are used in soak tank cleaners, spray cleaners, electrolytic cleaners, phosphatizing compounds, paint strippers, railroad car cleaners and maintenance cleaners.

Used in both alkaline and acid cleaners, they are compatible with caustic soda, silicates, carbonate, phosphates, sodium acid sulfate and many wetting agents. They are not compatible with cationic compounds.

Kelig is a recommended component for use in lubricant removal from zinc phosphate coatings. It may be used alone as a chelant, or blended with other chelants, such as sodium gluconate, sodium citrate, EDTA or NTA.

Maracarb N-1 has proved effective in controlling pulp mill pitch.

SOIL STABILIZATION AND DUST CONTROL

In the treatment of unsurfaced roads, **Norlig A** functions as soil stabilizer and dust control agent. Its soil stabilizing properties provide reduced maintenance costs, reduced frost heaving during spring break-up and base stabilization for subsequent oil seal treatment. **Norlig A** liquid, applied to open-pit mine roads, has proven an effective solution to the dust hazard and nuisance. The binding properties of **Norlig A** make it well suited for this use in semi-arid regions.

LEAD ACID STORAGE BATTERIES

Maracell XC, Marasperse CBX-2 and **Marasperse CBOs-3** have become accepted as efficient organic expanders in negative plates of lead acid storage batteries. They control the structure of lead sulfate crystals formed during discharge, boosting low temperature capacity at high discharge rates. By reducing polarization of the negative electrode, they also provide longer battery life. The expanders give lead electrodes higher surface areas than when expanders are not used.

CARBON BLACK AND PIGMENTS

Marasperse CBOs-3 is a versatile, economical anionic dispersant for various fillers and pigments, including carbon blacks. Stable, high-solids, temperature-resistant suspensions of carbon black can be made with either **Marasperse CBOs-3** or **Marasperse CBX-2.** Their dispersing potency results in greater fluidity at high solids concentration. Reduced milling time lowers manufacturing costs.

Norlig G and **Norlig 11d** are used as binders for pelletizing carbon black.

FOUNDRY

Goulac and **Glutrin** are used in large quantities at a savings by foundries as a partial (averaging around 33%) substitute for various core oils.

Goulac and **Glutrin** are also used in combination with corn-type cereals to replace core oil at a far reduced total binder cost. These two American Can products are also extensively used as tempering agents for various "block compounds," resulting in a core that is easier to clean out with attendant savings in labor costs.

ORE BENEFICIATION

American Can's lignosulfonates have demonstrated effectiveness in ore beneficiation, recovering formerly discarded fines and enhancing the electrolytic refining of ore.

Marasperse and **Norlig** help in dispersing metal and chemicals in the slurry of low-mineral-containing ore. Small quantities of these lignins increase the efficiency of the electrolyte in some electrolytic refining operations.

LINOLEUM PASTE

Norlig, in liquid form, is the product of choice in the manufacture of linoleum mastics which possess the needed workability and plasticity, meeting initial tack and bond strength requirements.

TANNING

Maratan products are low pH lignosulfonates processed for the tanning industry, formulated for a wide range of leathers, i.e., soft or mellow to firm types with desired temper.

For example, **Maratan SNV** imparts a soft, mellow character to the leather, while **Maratan 22** provides a firmer effect.

Maratan reduces tanning costs by replacing up to 50% of the normal requirements for vegetable tans. It can be used alone, or in conjunction with vegetable tannins, as a retan over chrome tanned leather.

TABLE 14

AMERICAN CAN COMPANY - LIGNIN PRODUCT APPLICATIONS

APPLICATIONS TO INDUSTRY, BY PRODUCT

	Agricultural Chemicals	Concrete	Cement	Dyestuff	Gypsum Boards	Ceramics	Water Treatment	Oil Well	Refractories	Briquetting	Animal Feed	Lead Acid Batteries	Carbon Black	Tanning	Industrial Cleaners	Emulsions
Americo																
SD-1	X			X	X		X									
Maraaperse																
52CP				X												
N-22	X			X			X								X	X
CBOs-3	X			X	X	X						X	X			
CBX-2	X			X		X						X	X			
B-22					X											
C-21	X	X			X	X										
N-3	X			X			X									
41g-3			X		X											
CR-23-6								X								
CR-23-7								X								
CR 23-9								X								
CE								X								X
CK								X								
Kelig																
32	X						X	X							X	
32-2	X						X								X	
Maracell																
XC	X											X				
XE	X						X					X			X	
Norlig																
A	X				X	X			X	X						
G			X						X	X			X			
H									X	X						
C		X							X							
11d										X			X			
11da	X															
21					X											
21-C		X	X		X											
412					X											
41-N						X			X							
NH	X					X					X					
Fe	X															
Zn	X															
Mn	X															
Mg	X															
Maracarb																
N-1	X			X											X	
N-2	X			X											X	
Additive-A						X			X							
Ameri-Bond											X					
Goulac						X			X	X						
Glutrin						X			X	X						
Maracon																
N		X														
T		X														
R		X														
MC		X														
Maratan																
SNV														X		
22														X		
SN														X		

TORULA YEAST

As previously indicated, Torula Yeast (Candida Utilis) is a strain of high protein wild yeast that has been selected to be used for the ethanol fermentation of the wood hydrolyzates. In addition, Torula Yeast(TY) has been identified as a co-product with ethanol and will be produced in a dried form in amounts of 2300 tons per year.

Torula Yeast currently has a wide range of applications in the food products industry. As a food grade product (suitable for human consumption), it is used primarily as a protein and vitamin supplement, meat extender, flavor enhancer, and food processing conditioner.

In general, Torula Yeast with various vitamin fortifications has been described as the total food ingredient that not only increases the protein and vitamin value of the food, but also enhances the functional characteristics of other ingredients such as starch and flavorings. (3) As a protein supplement and enhancer, TY has many applications. Some examples are: TY with a 50% protein content is used to partially replace hydrolyzed vegetable proteins (4). When processed with a sweet dairy whey, it is a partial replacement for nonfat dry milk proteins (5). Vitamin and protein enriched bakery and pasta products now prevalent in today's market are often made from flour containing TY and a various number of vitamins and minerals as enhancers. As an animal protein extender, TY is most often found in luncheon style meats like hot dogs, sausages, bologna, etc.

One unique characteristic of TY is its ability to enhance the natural flavors of the food ingredients it happens to be mixed with. As an example, it is able to impart richness and enhance the flavor of various chocolate products like cake mixes (1). Further, in sour cream based products it enhances the sour cream flavor in pourable or creamy type salad dressings. In this application it also increases the ability of the dressing to cling to vegetables, boosts emulsion stability and increases the flavor impact of seasonings.

The use of TY as a flavor enhancer is certainly one of its most varied and major applications in the food products industry. Another application is its use as a conditioner for food processing. For example, when added to various dough mixes, it reduces the mixing time by 25-30%. When potatoe chips and other related products are treated with TY before deep frying, the discoloration as a result of the frying is minimized, giving the product a higher visual appeal.

Journal research indicated that the food product manufacturers most likely to use Torula Yeast in the applications described above would be those who produce bakery goods, pastas, dressings, sausages, and luncheon meats, seasonings and flavorings, and animal feed.

To clarify these findings and to better identify the demand for Torula Yeast, 71 food product manufacturers were asked to respond to a use and demand questionaire. 43 of these manufacturers produced products as listed above which had a high liklihood of having Torula Yeast as an ingredient. The remaining 28 were manufacturers who represented the food product industry as a whole and less likely to use TY as ingredients.

The questionaire contained questions pertaining to:

1. Is the manufacturer now using TY
2. What products are manufactured that include TY as an ingredient
3. Will the manufacturer's demand for TY grow in the next five years.
4. What are the economics and practicability of using TY as an alternate ingredient.
5. Who are their current suppliers and are they able to satisfy their demand.
6. Types and quantities of TY used.

The results of this survey are summarized in Tables 15 and 16. As seen in Table 15, 9.3% of the manufacturers most likely to use TY (subsample A) were actually using it. This would clearly indicate a positive demand, though it may be relatively small in proportion to the size of the population. Further, when one examines the results it does not appear that this current demand will be static. Indeed, 7% of subsample A were making plans for new applications of TY and another 9.3% felt their demand would increase in five years. Some 11.6% and 9.3% of the manufacturers felt that TY could or possibly could functionally replace other ingredients they now use. If these manufacturers switched to TY, another increase in demand would occur. The likelihood of this happening is not clear. It seems that those manufacturers realizing that TY can replace their other ingredients will have to look closer at the economics of doing so. This is evident by the 34.9%

of the subsample stating that they are not sure about the economics of using TY as an alternate.

The domestic markets for TY are currently dominated by three manufacturers: Amoco, Boise-Cascade, and Lake States. The Amoco plant in Hutchinson, Minnesota, began the production of Torula Yeast in 1974, and uses petroleum based ethanol for the yeast growth. This facility produces annually 15 million pounds of primary yeast to serve as the basis for a variety of TY products. Boise-Cascade of Salem, Oregon, and Lake States of Rhinelander, Wisconsin, produce TY grown on the wood hydrolyzate from their respective paper mills. Boise-Cascade markets only the primary yeast while Lake States fortifies theirs with vitamins so as to offer a variety of products. Exhibits 1 and 2 summarize the products and product prices from these two manufacturers.

To summarize, it appears that a current and growing demand exists for TY in a certain segment of the food products industry. This segment would specifically include those manufacturers of bakery goods, pastas, flavoring and seasonings, sausages and luncheon meats, cream style dressings, and protein supplement products. Other manufacturers likely to use TY but not responding to the survey are companies manufacturing animal feeds and various dairy based products such as powdered milk and eggs. It appears that if TY is to enjoy greater demand in the future some effort will have to be made to better familiarize food manufacturers with its multiple uses and the economics of substituting TY for other ingredients.

Further investigation should also include the exploration of foreign markets. Such markets, particularly in the protein deprived nations, hold considerable potential for large demands of TY.

Although the domestic markets are presently dominated by the three manufacturers listed above, the demand for more production of TY seems to exist. Certainly the following excerpt from a letter from a Torula Yeast consumer to Montana Bio-Fuels would imply this:

> "Thank you for your letter and short description of your activities with the Montana State Department of Natural Resources and Conservation.........Our

laboratories and its associated companies have been in the yeast business since the early 1930's and.... market our products to the food, feed, and pharmaceutical industries throughout the world......... We would have interest in the full production of the Torula Yeast to be manufactured at this new facility (Thompson Falls) and talking with you in more detail........"

TABLE 15

SUMMARY OF THE USE AND DEMAND FOR TORULA YEAST AMONG 71 SELECTED FOOD PRODUCT MANUFACTURERS

(May, 1981)

Survey Questionaire Items	Percent of Total Sample (N=71)	Percent of Sample Deemed Most Likely to Use Torula Y
1. Currently using Torula Yeast		
"Yes" answers	5.6	9.3
2. Demand will increase in 5 years		
"Yes" answers	7.0	9.3
3. Planning for new applications of Torula Yeast in the next 5 fives		
"Yes" answers	4.2	7.0
"Maybe" answers	4.2	7.0
4. Can Torula Yeast satisfactorily replace functionally currently used ingredients?		
"Yes" answers	7.0	11.6
"Maybe" answers	5.6	9.3
5. Is it economical to use Torula Yeast as an alternate ingredient?		
"Yes" answers	1.4	2.3
"Not Sure"	21.1	34.9

TABLE 16

SUMMARY OF RESULTS FOR FOOD PRODUCTS MANUFACTURERS NOW USING TORULA YEAST (Sample Size 4)

(May, 1981)

Survey Questionaire Items	Percent of Total Responses
1. What grade of Torula Yeast do you use?	
Food Grade	100%
Fodder Grade	0
2. What type of your products include Torula Yeast as an ingredient?	
Bakery	25%
Pasta	25%
Luncheon Meats	25%
Protein Tablets and Powders	25%
3. From what manufacturers do you obtain Torula Yeast?	
Amoco	75%
Boise-Cascade	50%
Lake States	25%
4. Is your supplier able to satisfy your demand?	
Yes	100%
No	0

EXHIBIT 1

LAKE STATES
TORULA DRIED YEAST U.S.P. XIX

PRICE LIST

Rec'd 2-16-79

*TYPE B	$ 0.40/lb.
*TYPE 50	0.42/lb.
*TYPE 200	0.44/lb.
*TYPE CF-2	0.46/lb.
*TYPE 300	0.48/lb.
TYPE 361	1.00/lb.
TYPE 10-10-1	1.31/lb.
TYPE MDR	1.46/lb.

* 400 lbs. and less add 10.0¢/lb.
Over 400 lbs. to 1200 lbs. add 5.0¢/lb.
Over 1200 lbs. list price

PACKING: 200 lb. net fibre drums (standard)
Add 1¢/lb. for less than 200 lb. drums
Subtract 2¢/lb. for 50 lb. multiwall bags
(Type B only)

TERMS: Net 30 Days, F.O.B. Rhinelander, Wisconsin

PRICES EFFECTIVE MARCH 1, 1979 AND
SUBJECT TO CHANGE WITHOUT NOTICE

Manufactured and Distributed by America's Pioneer Producer
Lake States Division, Monarch Paper Corp.
Rhinelander, Wisconsin
715/369-4100
715/369-4356

CHARLES SCHULTZ, GEN. MGR.
KENNETH WHITACKER, ASST GEN MG

Lake States Division
MONARCH PAPER CORPORATION
Manufacturers
Rhinelander, Wisconsin 54501

EXHIBIT 1-A

LAKE STATES TORULA DRIED YEAST U.S.P. XIX

"LAKE STATES" TORULA DRIED YEAST U.S.P. XIX is a pure primary grown nutritional yeast produced in sterile media under conditions which permit, and controls which insure, the highest quality standards. LAKE STATES YEASTS in standard potencies are available to meet all the usual requirements for dried yeast. All types offered are guaranteed to meet or exceed the U.S.P. quality standards.

"LAKE STATES" STANDARD TYPES

TYPE	GUARANTEED POTENCIES* Thiamine	Riboflavin	Niacin	Protein	Pyridoxi
B	0.15	0.05	0.5	50%	
50	0.15	0.10	1.0	50%	
200	0.60	0.10	1.0	50%	
CF-2	0.60	0.20	1.0	50%	
300	0.90	0.10	1.0	50%	
361	3.00	6.00	1.0	50%	
10-10-1	10.00	10.00	1.0	50%	
MDR	3.0	4.0	30.0	50%	1.5

*Values are in milligrams per gram

STANDARD PACKING: 200 lb. fibre drums

SPECIAL PACKING: 100 lb. fibre drums at nominal additional charge

SPECIAL TYPES: Subject to process limitations, we can furnish special types differing from the above in vitamin potency or otherwise as may be required to fit specific applications.

GENERAL VITAMIN AND CHEMICAL DATA

Values for other B-complex factors as determined by the best available methods are given on the next page. These values are typical but are not guaranteed nor quoted as a condition of sale.

Lake States Division
MONARCH PAPER CORPORATION
Manufacturers

LAKE STATES
TORULA DRIED YEAST U.S.P. XIX

B-COMPLEX VITAMIN FACTORS (MICROGRAMS PER GRAM)

B_6 Pyridoxine	30-60
Pantothenic Acid	100-150
Free Folic Acid	1-3
PABA*	2500-3000
Inositol	3500-4500
Biotin	0.6-2.0
Vitamin B_{12} Activity	0.03-0.05

* Para-Amino Benzoic Acid

LAKE STATES TORULA DRIED YEAST U.S.P. XIX
(Proximate Composition - in Per Cent)

Protein N x 6.25	50-54
Non Protein N Average	0.3-0.5
Minerals, as Ash	7.0-7.8
Fiber A.O.A.C.	0.4-0.5
Carbohydrates	25-30
Moisture	4.5-7.0

MINERAL COMPOSITION
(Values expressed in mg. per gram of yeast unless otherwise noted)

Potassium	18-22
Phosphorus	15-20
Calcium	2-5
Magnesium	1.5-2.0
Silicon	0.3-0.5
Iron	0.15-0.2
Sodium	0.1-0.2
Zinc	0.1-0.15
Manganese	0.03-0.04
Aluminum	0.025-0.03
Copper	0.015-0.02
Iodine	0.004-0.005
Lead	0.003-0.004
Nickel	0.001-0.002
Cobalt	0.04 mcgm.

Lake States Division
MONARCH PAPER CORPORATION
Manufacturers
Rhinelander, Wisconsin 54501

Torula Dried Yeast

EXHIBIT 2

PRODUCT DATA SHEET

TYPE S

Boise Cascade produces Torula Dried Yeast, a primary grown yeast, at its facilities in Salem, Oregon. Type S is [illegible] primary grown yeast. Every effort has been made to produce a uniform, high quality product to meet the most rigid [illegible] for use in food products. Whatever you require from [illegible] flavor, protein, vitamins- you will find it in [illegible] product and you can now be assured of continued availability.

TYPICAL ANALYSIS*

Protein (N X 6.25)	50%
Thiamine	15 mcg/g
Riboflavin	40 mcg/g
Niacin	300 mcg/g
Fat	2%
Moisture	7%
Ash	8%
Salmonella	Negative
Coliform	Negative
Thermophiles	125/10 g
Flat Sours	50/10 g
Mold	50/g
Total Plate Count	7,500/g

1/80

*These potencies are representative only and are not to be considered as a condition of sale.

Boise Cascade Chemical Operations 1600 S.W. 4th Ave., Portland, Oregon 97201 - Telephone 503 224-7250

EXHIBIT 2-A

B-COMPLEX VITAMINS

Torula Yeast is a good source for all vitamins in the B-complex group. In addition to the potencies for thiamine, riboflavin and niacin, Type S will typically contain the following:

Vitamin	mcg./g.*
Pyridoxine (B_6)	35 - 60
Pantothenic Acid	100 - 150
Biotin	0.6 - 2
Inositol	3,500 - 4,500
Choline	2,500 - 3,000
para-Aminobenzoic Acid	15 - 25
B_{12}	0.003 - 0.005
Folic Acid	9 - 18
Free Folic Acid	Less than 1

Yeast preparations with other vitamin potencies are available from Boise Cascade Chemical Operations. Specifications will be furnished on request. Proprietary formulations can be made available subject to process limitations.

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*These potencies are representative only and are not to be considered as a condition of sale.

EXHIBIT 2-B

TYPICAL AMINO ACID COMPOSITION*
%, Protein Basis

Alanine	3.3 - 3.5
Arginine	5.3 - 5.5
Aspartic acid	4.5 - 4.7
Cystine	0.4 - 1.0
Glutamic acid	14.7 -15.2
Glycine	4.7 - 5.1
Histidine	1.8 - 1.9
**Isoleucine	4.6 - 5.7
**Leucine	6.7 - 7.3
**Lysine	6.5 - 6.9
**Methionine	1.0 - 1.3
**Phenylalanine	4.2 - 4.6
Proline	3.5 - 3.6
Serine	5.1 - 5.9
**Threonine	5.3 - 5.7
**Tryptophan	1.1 - 1.3
Tyrosine	3.3 - 3.4
**Valine	6.2 - 6.5

**Essential amino acids
*These potencies are representative only and are not to be considered as a condition of sale.

MINERALS CONTENT

Torula Yeast contains various minerals in the approximate quantities shown below:

	%		ppm
Potassium	1.80 - 2.20	Copper	15 - 17
Sodium	0.01 - 0.02	Manganese	32 - 34
Calcium	0.85 - 0.95	Aluminum	25 - 27
Phosphorus	1.50 - 1.90	Lead	1.3 - 1.5
Magnesium	0.15 - 0.25	Cobalt	0.03 - 0.05
Silicon	0.04 - 0.06	Nickel	1.5 - 1.7
Sulfur	0.50 - 0.80	Iodine	2.0 - 3.1
Iron	0.015 - 0.016	Chloride	0.25 - 0.35
Zinc	0.012 - 0.013		

The information given in this product data sheet is to the best of our knowledge accurate. It is intended to be helpful but no warranty is expressed or implied regarding the accuracy of such data. It is the user's responsibility to determine the suitability for his own use of the products described herein; and since conditions of use are beyond our control, BOISE CASCADE HEREBY DISCLAIMS ALL WARRANTIES EXPRESSED OR IMPLIED INCLUDING ANY IMPLIED WARRANTY OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE.

Torula Dried Yeast

EXHIBIT 2-D

PRICE SCHEDULE

EFFECTIVE OCTOBER 1, 1980

TORULA DRIED YEAST - TYPE S	Price Per Pound F.O.B. Salem, Oregon
10,000 lbs. or more	$0.49
5,000 lbs. to 9,999 lbs.	0.54
less than 4,999 lbs.	0.59

For Ex-Warehouse Chicago Shipments Add $0 05 Per Pound

PALLETIZING

Add 30¢/cwt for 50 lb. bags on nonreturnable wooden pallets.

PACKAGING

50 lb. Multiwall Bags	Standard
100 lb. Net Fibre Drums	Add $0.06/lb.
150 lb. Net Fibre Drums	Add $0.05/lb.
200 lb. Net Fibre Drums	Add $0.04/lb.

TERMS

Net 30 Days - No Discount

THE ABOVE PRICES ARE SUBJECT TO CHANGE WITHOUT NOTICE

Boise Cascade Chemical Operations 1600 S.W. 4th Ave., Portland, Oregon 97201 - Telephone: 503/224-7250

REFERENCES

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2. Brogna, Oykue (Editor) "A Range of Chemicals Based on Biomass Feedstocks Could Form the Bases of Highly Profitable New Chemical Ventures" Biomass Digest, Vol. 2, No. 12, pg. 1, December 1980

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ECONOMIC ANALYSIS

DISCUSSION OF ECONOMIC ANALYSIS

The approach on analyzing the economic feasibility of a plant to produce fuel grade ethanol and Torula Yeast was that the plant concept and operating results as initially prepared by BEI would be expanded to include three additional plants; one modified to produce food grade yeast versus fodder grade yeast, one utilizing Stake Technology in the hydrolysis phase of production, and yet another which would provide co-generated electricity from waste wood generally available at $15 per ton. These are, respectively, plant concepts #2, #3, and #4. (Additional assumptions, constraints, and projections on which the analysis was based are discussed later in this section.

A one year projection of cash flow after income taxes was prepared for each plant concept assuming selling prices of $2.00 and $2.25 per gallon of fuel grade ethanol (Table 12). The resulting cash flows were then analyzed using the net present value method. (Discussed later in this section) The results, as shown in Table 1, were very encouraging, and made it apparent that each modification added to the economic value of the plant by increasing returns. Because of this, and the fact that the net present values that resulted for 10% and 15% rates of return were so large, it was decided to combine all four plant concepts into a plant concept #5, and expand the range of the analysis by including another selling price ($1.75/gal FGE) and varying the cost of raw material for production of FGE by increasing it 33 1/3%. (Table 13)

After discussion, it was decided that the net present value method of analysis needed further clarification to better enable a reader to make decisions about the economic feasibility of the study. Therefore, the results from Table 12 and 13 were used to compute an internal rate of return, or a time-adjusted rate of return, for the cash flows from each concept. This method tells a potential investor more precisely what the return should be from building and operating the plant. (See Table 14, Summary of IRR's) The lowest rate of return, at a selling price of $1.75/gal for FGE and 33 1/3% increased raw material costs, turned out to be an attractive 31.2%, with the highest potential investment being 98.1%.

Based on the projected plant construction and operating costs, and the assumed results of operations for each plant concept analyzed, it appears that any of the plant designs would be economically feasible. Plant concept #5 does present the best apportunity for success since it projects the largest cash flow and, therefore, the highest returns on investment. Further refinement and study of the projected costs and capabilities should provide enough data and reliability to present this project to potential investors. If this project is properly structured to take advantage of available tax credits and write offs by passing them through to the investors, it has a high probability of going into production.

ASSUMPTIONS AND CONSTRAINTS

DEBT RETIREMENT for the 80% financing has been computed on a 20 year amortization schedule at 15% interest rates.

INCOME TAXES have been computed for rates of income in effect December 31, 1980, giving effect to depreciation tax shield of a 10 year straight line write off.

CASH FLOW computations are after debt retirement and income taxes and give effect to the 20% Investment Tax Credit available for Bio-Mass production.

DISCOUNTED CASH FLOW analysis has been done for a 10% and 15% minimum designed yield for investors.

INVESTMENT INCOME from excess cash flow has not been given effect in this analysis.

INFLATION AND CHANGING PRICES have not been considered, to simplify the analysis and because they would be extremely difficult to qualify.

330 OPERATING DAYS per year has been used for cost and income computations.

The economic analysis has been based on the following assumptions and projections:

PLANT COST estimates have been prepared by Brelsford Engineering Inc. of Bozeman, Montana, based upon technical papers prepared by Dr. Wayman of the University of Toronto and Dr. O'Neil of Georgia Institute of Technology. See Conceptual Engineering Plan, page 101-104.

OPERATING COST estimates have been prepared by Brelsford Engineering, Inc. of Bozeman, Montana, based upon technical papers referred to above. These operating costs have been modified to account for the four types of production capabilities described below. Costs have been assumed to be stable. See Conceptual Engineering Plan, pages 101-104.

PRODUCTION CAPABILITIES and the corresponding profits and cash flows have been analyzed for the following four plant types:

> PLANT CONCEPT #1 - This is the basic plant model as defined by BEI. Production capabilities are 2.4 million gallons per year of fuel grade ethanol (FGE) and 2300 tons per year of fodder grade yeast.
>
> PLANT CONCEPT #2 - This is the basic plant model as defined by BEI, modified to produce food grade yeast. This increases the plant cost by $263,000 for stainless steel components in the fermentation process, and increases sales income by $100 per ton for yeast, or $130,000 per year. Production capabilities are 2.4 million gallons per year of FGE and 2300 tons per year of food grade yeast.
>
> PLANT CONCEPT #3 - This is the basic plant model as defined by BEI, modified to use Stake Co. technology in the hydrolysis process. This decreases plant cost by $221,000. Nothing else changes. Production capabilities are 2.4 million gallons per year of FGE and 2300 tons per year of fodder grade yeast.
>
> PLANT CONCEPT #4 - This is the basic plant model as defined by BEI, with the addition of equipment to generate electricity in amounts large enough to sell.

The cogeneration equipment increases the plant cost by $763,000, and provides all of the plant usage and 750 kilo watts excess power to be sold. The 750 kw for 330 production days per year at 43 mills ($.043) per kw hour produces income of $255,000. The savings on plant utility costs would be $500,000 for an income effect of $755,000. Increased raw material cost would be $15 per ton for 85 tons per day, or $420,000 per year. The cost of the raw material for cogeneration has been priced at $15 per oven dry ton (ODT), which approximates the cost of purchasing and transporting hog fuel and other mill residue in the plant vacinity. Production capabilities are 2.4 million gallons per year of FGE, 2300 tons per year of fodder grade yeast, and excess electricity of 750 kw per hour (5.9 megawatt hours per year).

PLANT CONCEPT #5 - This is the basic plant model as defined by BEI, with the addition of equipment to generate electricity in amounts large enough to sell and modified to produce food grade yeast. (See plant concept numbers 3 and 4 for details) The net effect of the changes on this model, in comparison to plant concept #1, is that raw material cost is up by $420,000 per year; sales income is up $230,000 for yeast and $255,000 for electricity; utility costs are zero for a decrease in costs of $500,000; The sum of the changes is to increase net cash flow by $565,000 per year over the cash flow generated by the basic plant model. Production capabilities are 2.4 million gallons per year of FGE, 2300 tons per year of food grade yeast. and excess electricity of 750 kw per hour (5.9 megawatt hours per year)

SALES PRICES of $2.00 and $2.25 per gallon have been used for the fuel grade alcohol (See page 38), and $700 per ton for fodder grade yeast and $800 per ton for food grade yeast. The cogenerated excess electricity has been priced at $.043 (cost of power to the Bonneville Power Administration).

EQUITY INVESTMENT of 20% has been used for the analysis, with 80% of plant cost to be financed.

EXPLANATION OF NET PRESENT VALUE METHOD OF CASH FLOW ANALYSIS

The net present value method of analyzing the discounted cash flows is a simple concept. A projection is made of future cash flows, preferably after tax considerations, and then these cash flows are discounted to a present value based on a predetermined minimum acceptable return on investment. This may be any rate the investor desires. In this analysis we have made computations for 10% and 15% rate of return (ROR).

Once the incremental cash flows for a given project have been discounted to present values and summarized, the investment cost is subtracted from the total reached and if the result is a positive number, then the project should be undertaken.

TABLE 1

SUMMARY OF DISCOUNTED CASH FLOW ANALYSIS FOR PROPOSED PLANT ALTERNATIVES WITH THE NET PRESENT VALUE METHOD

(PER 1000 DOLLARS) AND ALL SUBSEQUENT TABLES

	10% ROR		15% ROR	
	$2.00/gal	$2.25/gal	$2.00/gal	$2.25/gal
Plant Concept #1				
Discounted cash flow	$7,992	$10,591	$6,582	$8,796
Investment	2,180	2,180	2,180	2,180
Net present value	$5,812	$8,411	$4,402	$6,616
Plant Concept #2				
Discounted cash flow	$9,077	$11,286	$7,482	$9,386
Investment	2,233	2,233	2,233	2,233
Net present value	$6,844	$ 9,053	$5,249	$7,153
Plant Concept #3				
Discounted cash flow	$8,146	$10,588	$6,706	$8,796
Investment	2,136	2,136	2,136	2,136
Net present value	$6,010	$ 8,452	$4,570	$6,660
Plant Concept #4				
Discounted cash flow	$8,948	$11,605	$7,614	$9,642
Investment	2,333	2,333	2,333	2,333
Net present value	$6,615	$ 9,272	$5,281	$7,309
Plant Concept #5				
Discounted cash flow	$10,027	$12,252	$8,290	$10,191
Investment	2,385	2,385	2,385	2,385
Net present value	$ 7,642	$ 9,867	$5,905	$ 7,806

TABLE 2

DISCOUNTED CASH FLOW ANALYSIS OF PROPOSED PLANT TO CONVERT WOOD WASTE TO FUEL ALCOHOL AND YEAST

(PER 1000 DOLLARS)

Net Present Value Computation for Plant Concept #1

	10 year cash flow (at $2.00/gal FGE)	Present Value Factor 15% ROR	Present Value
Year 1	$1,360	.870	$1,183
Year 2	1,360	.756	1,028
Year 3	1,360	.658	895
Year 4	1,360	.572	778
Year 5	1,360	.497	676
Year 6	1,360	.432	588
Year 7	1,360	.376	511
Year 8	1,091	.327	357
Year 9	1,075	.284	305
Year 10	1,057	.247	261
	$ 12,743		$7,992
	(at $2.25/gal FGE)		
Year 1	$1,960	.870	$1,705
Year 2	1,960	.756	1,482
Year 3	1,960	.658	1,290
Year 4	1,960	.572	1,121
Year 5	1,686	.497	838
Year 6	1,440	.432	622
Year 7	1,428	.376	537
Year 8	1,415	.327	463
Year 9	1,399	.284	397
Year 10	1,381	.247	341
	$ 16,589		$8,796

TABLE 3

DISCOUNTED CASH FLOW ANALYSIS OF PROPOSED PLANT TO CONVERT WOOD WASTE TO FUEL ALCOHOL AND YEAST

Net Present Value Computation for Plant Concept #1

	10 year cash flow (at $2.00/gal FGE)	Present Value Factor 10% ROR	Present Value
Year 1	$1,360	.909	$1,236
Year 2	1,360	.826	1,123
Year 3	1,360	.751	1,021
Year 4	1,360	.683	929
Year 5	1,360	.621	845
Year 6	1,360	.564	767
Year 7	1,360	.513	698
Year 8	1,091	.467	509
Year 9	1,075	.424	456
Year 10	1,057	.386	408
	$ 12,743		$7,992
	(at $2.25/gal FGE)		
Year 1	$1,960	.909	$1,782
Year 2	1,960	.826	1,619
Year 3	1,960	.751	1,472
Year 4	1,960	.683	1,339
Year 5	1,686	.621	1,047
Year 6	1,440	.564	812
Year 7	1,428	.513	733
Year 8	1,415	.467	661
Year 9	1,399	.424	593
Year 10	1,381	.386	533
	$ 16,589		$10,591

TABLE 4

DISCOUNTED CASH FLOW ANALYSIS OF PROPOSED PLANT TO CONVERT WOOD WASTE TO FUEL ALCOHOL AND YEAST

Net Present Value Computation for Plant Concept #2

	10 year cash flow (at $2.00/gal FGE & $800./ton yeast)	Present Value Factor 10% ROR	Present Value
Year 1	$1,553	.909	$1,412
Year 2	1,553	.826	1,283
Year 3	1,553	.751	1,166
Year 4	1,553	.683	1,061
Year 5	1,553	.621	964
Year 6	1,553	.564	876
Year 7	1,553	.513	797
Year 8	1,204	.467	562
Year 9	1,188	.424	504
Year 10	1,170	.386	452
	$ 14,433		$9,077
	(at $2.25/gal FGE)		
Year 1	$2,153	.909	$1,957
Year 2	2,153	.826	1,778
Year 3	2,153	.751	1,617
Year 4	1,995	.683	1,363
Year 5	1,565	.621	972
Year 6	1,554	.564	876
Year 7	1,542	.513	791
Year 8	1,528	.467	714
Year 9	1,512	.424	641
Year 10	1,494	.386	577
	$ 17,649		$11,286

TABLE 5

DISCOUNTED CASH FLOW ANALYSIS OF PROPOSED PLANT TO CONVERT WOOD WASTE TO FUEL ALCOHOL AND YEAST

Net Present Value Computation for Plant Concept #2

	10 year cash flow (at $2.00/gal FGE & $800./ton yeast)	Present Value Factor 15% ROR	Present Value
Year 1	$1,553	.870	$1,351
Year 2	1,553	.756	1,174
Year 3	1,553	.658	1,022
Year 4	1,553	.572	888
Year 5	1,553	.497	772
Year 6	1,553	.432	671
Year 7	1,553	.376	584
Year 8	1,204	.327	394
Year 9	1,188	.284	337
Year 10	1,170	.247	289
	$14,443		$7.482
	(at $2.25/gal FGE)		
Year 1	$2,153	.870	$1,873
Year 2	2,153	.756	1,628
Year 3	2,153	.658	1,417
Year 4	1,995	.572	1,141
Year 5	1,565	.497	778
Year 6	1,554	.432	671
Year 7	1,542	.376	580
Year 8	1,528	.327	500
Year 9	1,512	.284	429
Year 10	1,494	.247	369
	$ 17,649		$ 9,386

TABLE 6

DISCOUNTED CASH FLOW ANALYSIS OF PROPOSED PLANT TO CONVERT WOOD WASTE TO FUEL ALCOHOL AND YEAST

Net Present Value Computation for Plant Concept #3

	10 year cash flow (at $2.00/gal FGE)	Present Value Factor 10% ROR	Present Value
Year 1	$1,385	.909	$1,259
Year 2	1,382	.826	1,144
Year 3	1,385	.751	1,040
Year 4	1,385	.683	946
Year 5	1,385	.621	860
Year 6	1,385	.564	781
Year 7	1,385	.513	711
Year 8	1,115	.467	521
Year 9	1,100	.424	466
Year 10	1,082	.386	418
	$12,992		$ 8,146
	(at $2.25/gal FGE)		
Year 1	1,985	.909	$1,804
Year 2	1,985	.826	1,640
Year 3	1,985	.751	1,491
Year 4	1,974	.683	1,348
Year 5	1,474	.621	915
Year 6	1,464	.564	826
Year 7	1,452	.513	745
Year 8	1,439	.467	672
Year 9	1,424	.424	604
Year 10	1,406	.386	543
	$ 16,588		$10,588

TABLE 7

DISCOUNTED CASH FLOW ANALYSIS OF PROPOSED PLANT TO CONVERT WOOD WASTE TO FUEL ALCOHOL AND YEAST

Net Present Value Computation for Plant Concept #3

	10 year cash flow (at $2.00/gal FGE)	Present Value Factor 15% ROR	Present Value
Year 1	$1,385	.870	$1,205
Year 2	1,385	.756	1,047
Year 3	1,385	.658	911
Year 4	1,385	.572	792
Year 5	1,385	.497	688
Year 6	1,385	.432	598
Year 7	1,385	.376	521
Year 8	1,115	.327	365
Year 9	1,100	.284	312
Year 10	1,082	.247	267
	$ 12,992		$ 6,706
	(at $2.25/gal FGE)		
Year 1	$ 1,985	.870	$ 1,727
Year 2	1,985	.756	1,501
Year 3	1,985	.658	1,306
Year 4	1,974	.572	1,129
Year 5	1,474	.497	733
Year 6	1,464	.432	632
Year 7	1,452	.376	546
Year 8	1,439	.327	471
Year 9	1,424	.284	404
Year 10	1,406	.247	347
	$ 16,588		$ 8,796

TABLE 8

DISCOUNTED CASH FLOW ANALYSIS OF PROPOSED PLANT TO CONVERT WOOD WASTE TO FUEL ALCOHOL AND YEAST

Net Present Value Computation for Plant Concept #4

	10 year cash flow (at $2.00/gal FGE)	Present Value Factor 10% ROR	Present Value
Year 1	$1,575	.909	$ 1,432
Year 2	1,575	.826	1,301
Year 3	1,575	.751	1,183
Year 4	1,575	.683	1,076
Year 5	1,575	.621	978
Year 6	1,575	.564	888
Year 7	1,575	.513	808
Year 8	1,236	.467	585
Year 9	1,236	.424	524
Year 10	1,217	.386	470
	$ 14,730		$8,948
	(at $2.25/gal FGE)		
Year 1	$ 2,175	.909	$1,977
Year 2	2,175	.826	1,797
Year 3	2,175	.751	1,633
Year 4	2,170	.683	1,482
Year 5	1,615	.621	1,003
Year 6	1,604	.564	905
Year 7	1,591	.513	816
Year 8	1,577	.467	736
Year 9	1,560	.424	661
Year 10	1,541	.386	595
	$ 18,183		$11,605

TABLE 9

DISCOUNTED CASH FLOW ANALYSIS OF PROPOSED PLANT TO CONVERT WOOD WASTE TO FUEL ALCOHOL AND YEAST

Net Present Value Computation for Plant Concept #4

	10 year cash flow (at 2.00/gal FGE)	Present Value Factor 15% ROR	Present Value
Year 1	$ 1,575	.870	$ 1,370
Year 2	1,575	.756	1,191
Year 3	1,575	.658	1,036
Year 4	1,575	.572	901
Year 5	1,575	.497	783
Year 6	1,575	.432	680
Year 7	1,575	.376	592
Year 8	1,252	.327	409
Year 9	1,236	.284	351
Year 10	1,217	.247	301
	$14,730		$7,614
	(at $2.25/gal FGE)		
Year 1	$ 2,175	.870	$1,892
Year 2	2,175	.756	1,644
Year 3	2,175	.658	1,431
Year 4	2,175	.572	1,241
Year 5	1,615	.497	803
Year 6	1,604	.432	693
Year 7	1,591	.376	598
Year 8	1,577	.327	516
Year 9	1,560	.284	443
Year 10	1,531	.247	381
	$ 18,183		$9,642

TABLE 10

DISCOUNTED CASH FLOW ANALYSIS OF PROPOSED PLANT TO CONVERT WOOD WASTE TO FUEL ALCOHOL AND YEAST

Net Present Value Computation for Plant Concept #5

	10 year cash flow (at $2.00/gal FGE)	Present Value Factor 10% ROR	Present Value
Year 1	$ 1,762	.909	$1,602
Year 2	1,762	.826	1,455
Year 3	1,762	.751	1,323
Year 4	1,762	.683	1,203
Year 5	1,762	.621	1,094
Year 6	1,695	.564	956
Year 7	1,360	.513	698
Year 8	1,344	.467	628
Year 9	1,328	.424	563
Year 10	1,309	.386	505
	$15,846		$10,027
	(at 2.25/gal FGE)		
Year 1	$ 2,362	.909	$ 2,147
Year 2	2,362	.826	1,951
Year 3	2,362	.751	1,774
Year 4	2,028	.683	1,385
Year 5	1,709	.621	1,061
Year 6	1,698	.564	958
Year 7	1,685	.513	864
Year 8	1,670	.467	780
Year 9	1,653	.424	701
Year 10	1,634	.386	631
	$19,163		$12,252

TABLE 11

DISCOUNTED CASH FLOW ANALYSIS OF PROPOSED PLANT TO CONVERT WOOD WASTE TO FUEL ALCOHOL AND YEAST

Net Present Value Computation for Plant Concept #5

	10 year cash flow (at $2.00/gal FGE)	Present Value Factor 15% ROR	Present Value
Year 1	$ 1,762	.870	$ 1,533
Year 2	1,762	.756	1,332
Year 3	1,762	.658	1,159
Year 4	1,762	.572	1,008
Year 5	1,762	.497	876
Year 6	1,695	.432	732
Year 7	1,360	.376	511
Year 8	1,344	.327	439
Year 9	1,328	.284	377
Year 10	1,309	.247	323
	$15,846		$ 8,290
	(at $2.25/gal FGE)		
Year 1	$ 2,362	.870	$ 2,055
Year 2	2,362	.756	1,786
Year 3	2,362	.658	1,554
Year 4	2,028	.572	1,160
Year 5	1,709	.497	849
Year 6	1,698	.432	734
Year 7	1,685	.376	634
Year 8	1,670	.327	546
Year 9	1,653	.284	469
Year 10	1,634	.247	404
	$ 19,163		$10,191

TABLE 12

SUMMARY OF PLANT CONCEPTS

	FGE at $2.00/gal					FGE at $2.25/gal				
	Plant Concept 1	Plant Concept 2	Plant Concept 3	Plant Concept 4	Plant Concept 5	Plant Concept 1	Plant Concept 2	Plant Concept 3	Plant Concept 4	Plant Concept 5
Plant Cost	$ 9,600	$ 9,863	$ 9,380	$10,363	$10,406	$ 9,600	$ 9,863	$ 9,380	$10,363	$10,406
Working Capital	1,300	1,300	1,300	1,300	1,300	1,300	1,300	1,300	1,300	1,300
	$10,900	$11,163	$10,680	$11,663	$11,706	$10,900	$11,163	$10,680	$11,663	$11,706
Sales - FGE	$ 4,800	$ 4,800	$ 4,800	$ 4,800	$ 4,800	$ 5,400	$ 5,400	$ 5,400	$ 5,400	$ 5,400
- Yeast	1,610	1,840	1,610	1,610	1,840	1,610	1,840	1,610	1,610	1,840
- Excess Electricity	0	0	0	255	225	0	0	0	255	255
Total Cash In	$6,410	$6,640	$6,410	$6.665	$6,865	$ 7,010	$ 7,240	$ 7,010	$ 7,265	$ 7,465
Cost of Manufacturing										
- Wood Waste	$1,140	$1,140	$1,140	$1,140	$1,140	$ 1,140	$ 1,140	$ 1,140	$ 1,560	$ 1,560
- Chemicals	390	390	390	390	390	390	390	390	390	390
- Labor and Supervision	570	570	570	570	570	570	570	570	570	570
- Utilities	500	500	500	0	0	500	500	500	0	0
- Maintenance	380	330	380	400	400	380	380	380	400	400
- Miscellaneous	450	450	450	450	450	450	450	450	450	450
	$3,430	$3,430	$3.430	$3,370	$3,370	$ 3,430	$3,430	$ 3,430	$ 3,370	$ 3,370
General and Administrative	230	230	230	230	230	230	230	230	230	230
Debt Retirement and Interest	1,390	1,427	1,365	1,490	1,504	1,390	1,427	1,365	1,490	1,505
Total Cash Out	$5,050	$5,087	$5,025	$5,090	$5,104	$ 5,050	$5,087	$5,025	$5,090	$5,104
Net Cash Flow Before Taxes	$1,360	$1,553	$1,385	$1,575	$1.762	$1,960	$2,153	$1,985	$2,175	$2,362
Cash Flow After Taxes, Assuming Depreciation of 10%/yr and Investment Tax Credit of 20% of Plant Cost; (Principle Portion of debt retirement is not a deduction for tax purposes)										
Year 1	$1,360	$1,553	$1,385	$1,575	$1,762	$1,960	$2,153	$1,985	$2,175	$2,362
Year 2	1,360	1,553	1,385	1,575	1,762	1,960	2,153	1,985	2,175	2,362
Year 3	1,360	1,553	1,385	1,575	1,762	1,960	2,153	1,985	2,175	2,362
Year 4	1,360	1,553	1,385	1,575	1,762	1,960	2,153	1,985	2,175	2,362
Year 5	1,360	1,553	1,385	1,575	1,762	1.686	1,995	1,974	2,170	2,028
Year 6	1,360	1,553	1,385	1,575	1,695	1,440	1,565	1,474	1,615	1,709
Year 7	1,360	1,553	1,385	1,575	1,360	1,428	1,554	1,464	1,604	1,698
Year 8	1,091	1,204	1,115	1,252	1,344	1,415	1,542	1,452	1,591	1,685
Year 9	1,075	1,188	1,100	1,236	1,328	1,399	1,528	1,439	1,577	1,670
Year 10	1,057	1,170	1,082	1,217	1,309	1,381	1,494	1,406	1,560	1,653
	$12,743	$14,433	$12,992	$14,730	$15,846	$16,589	$17,649	$16,588	1,541	1,634
									$18,183	$19,163

TABLE 13

EXPANDED ANALYSIS OF PLANT CONCEPT #5

	Plant Concept #5 With Three Selling Prices FGE			Plant Concept #5 With Three Selling Prices and 33% Increase in Raw Material Costs		
	$1.75/gal	$2.00/gal	$2.25/gal	$1.75/gal	$2.00/gal	$2.25/gal
Plant Cost	$10,406	$10,405	$10,406	$10,406	$10,406	$10,406
Working Capital	1,300	1,300	1,300	1,300	1,300	1,300
	$11,706	$11,706	$11,706	$11,706	$11,706	$11,706
Sales - FGE	$4,200	$4,800	$5,400	$4,200	$4,800	$5,400
- Yeast	1,840	1,840	1,840	1,840	1,840	1,840
- Excess Electricity	225	225	225	225	225	225
Total Cash In	$6,265	$6,865	$7,465	$6,265	$6,865	$7,465
Cost of Manufacturing						
- Wood Waste	$1,560	$1,560	$1,560	$1,940	$1,940	$1,940
- Chemicals	390	390	390	390	390	390
- Labor and Supervision	570	570	570	570	570	570
- Utilities	0	0	0	0	0	0
- Maintenance	400	400	400	400	400	400
- Miscellaneous	450	450	450	450	450	450
	$3,370	$3,370	$3,370	$3,370	$3,370	$3,370
General and Administrative	230	230	230	230	230	230
Debt Retirement and Interest	1,504	1,504	1,504	1,504	1,504	1,504
Total Cash Out	$5,104	$5,104	$5,104	$5,484	$5,484	$5,484
Net Cash Flow Before Taxes	$1,162	$1,762	$2,362	$ 781	$1,381	$1,981
Cash Flow After Taxes, Assuming Depreciation of 10%/yr and Investment Tax Credit of 20% of Plant Cost (Principal portion of debt retirement is not a deduction for tax purposes)						
Year 1	$ 1,162	$ 1,762	$ 2,362	$ 781	$ 1,381	$ 1,981
Year 2	1,162	1,762	2,362	781	1,381	1,981
Year 3	1,162	1,762	2,362	781	1,381	1,981
Year 4	1,162	1,762	2,028	781	1,381	1,981
Year 5	1,162	1,762	1,709	781	1,381	1,878
Year 6	1,162	1,695	1,698	781	1,381	1,492
Year 7	1,162	1,360	1,685	781	1,381	1,479
Year 8	1,021	1,344	1,670	781	1,140	1,464
Year 9	1,004	1,328	1,653	781	1,123	1,447
Year 10	985	1,309	1,634	781	1,104	1,428
	$11,144	$15,846	$19,163	$7,810	$13,034	$17,112

TABLE 14

SUMMARY OF INTERNAL RATES OF RETURN

	IRR's FOR SELLING PRICES OF:		
	$1.75/gal	$2.00/gal	$2.25/gal
Plant Concept #1	-	61.5%	88.3%
Plant Concept #2	-	68.8%	93.9%
Plant Concept #3	-	64.1%	90.9%
Plant Concept #4	-	66.8%	91.3%
Plant Concept #5	48.4%	74.3%	98.1%
Plant Concept #5 (with 33 1/3% cost increase in raw material)	31.2%	58.1%	83.3%

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